GEOFLUX (PTY) LTD

REPUBLIC OF BOTSWANA

Ministry of Mineral Resources and Water Affairs

Department of Water Affairs

INTEGRATED RURAL VILLAGE WATER SUPPLY PROGRAMME SITING OF BOREHOLES AND SUPERVISION OF DRILLING, CONSTRUCTION AND PUMPING TEST WORKS IN HUKUNTSI, LEHUTUTU AND TSHANE

INCEPTION REPORT

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1.0 INTRODUCTION

1.1 Background

The village water supply project for Hukuntsi-Lehututu-Tshane was awarded Geoflux by the Department of Water Affairs on 10th November 1993. This project is carried out under the general framework of the Integrated Rural Village Water Supply Programme.

Numerous boreholes have been drilled, over the years, in the immediate vicinity of Hukuntsi, Lehututu and Tshane in an attempt to provide potable drinking water to the inhabitants of the three villages. These drilling operations have generally been unsuccessful in terms of meeting the water requirements for these villages because of low yields in boreholes with potable water and saline water in deep high yielding boreholes.

In 1989/90 the Department of Water Affairs drilled five (5) boreholes in Lehututu to meet the water demand of the three villages. These boreholes were drilled in a shallow perched aquifer in the Kalahari beds and are producing a cumulative extractable yield of approximately 5 m^3/h with an average TDS of 500 mg/l.

Deep drilling was also undertaken during the same period (1989/90) in the arkosic sandstone of lower/middle Ecca and groundwater was encountered under confined conditions at average depths of 375 m with piezometric levels around 90 mbgl. Blow out yields of these deep boreholes range from 12 to 44 m^3/h but the water quality indicated TDS in excess of 10000 mg/l. The water is predominantly of a NaCl chemical affinity.

The present water demand for the three villages is estimated at 238 m^3/day but is projected to increase, due to increasing population, to 350 m^3/day and 724 m^3/day for the years 2000 and 2020 respectively. The present water supply is estimated at 100 m^3/day resulting in a water demand short fall of 138 m^3/day.

1.2 Project Objectives

The main objective of the Integrated Rural Village Water Supply Programme is to provide the rural populations of Botswana with reliable, sufficient and potable water supply. The project aims at assessing and evaluating the potable groundwater resources of the perched Kalahari beds and Ntane sandstone aquifers within 20km radius of the centre of the three villages. To fulfil the aim and objective of the project, the general approach outlined below will be followed:

- determining the most effective borehole siting and drilling techniques as well as borehole designs making groundwater development in the investigation area possible in an optimal and most economical way;

- studying, in detail, the nature of the perched Kalahari beds aquifer and to determine its geometry (areal extent, lithology and thickness);
- determining aquifer parameters (transmissivity, storativity, hydraulic gradients) for the perched Kalahari beds and Ntane sandstone aquifers;
- supervising drilling and test pumping in a professional way;
- determining groundwater quality and chemical provinces and delineating areas with potable groundwater;
- quantifying the potable groundwater resources that can be economically developed and recommending rates of abstraction and pump settings;
- calculating the aquifer lifetime under various assumed abstraction scenarios;
- identifying sites for drilling production boreholes best suited to economically meet the water supply requirements of Tshane, Hukuntsi and Lehututu villages;
- determining recharge areas and rates of recharge to the perched Kalahari beds aquifer and Ntane sandstone aquifer.
- investigating and assessing possible environmental impacts and adverse effects on existing users that may be caused by the proposed utilisation of the groundwater resources.

1.3 PROJECT SETTING

1.3.1 Location and Access

The project area is situated in the Kgalagadi District and consists of an area of 20 km radius of the centre of Tshane, Hukuntsi and Lehututu villages. The location of the project area is shown on map Figure 1.3.1. The three villages form a triangle with almost equal distances from each other of 10 to 15 km.

The project area is accessed by tarred road from Gaborone to Sekoma (255 km) followed by gravel/sand road to Kang (150km) and turning south-west for 105 km (75 km tar and 30 km sand/gravel). The three villages are each situated near big pans from which their names are derived.

1.3.2 Geomorphology

The project area lies on flat land gently sloping to the south. There are numerous pans of varying sizes (the largest being Tshane pan ~1 km x 5 km) with a north-south elongation. The pans are mostly bounded on the southern side by sand dunes. There are no rivers and fossil valleys in the area.

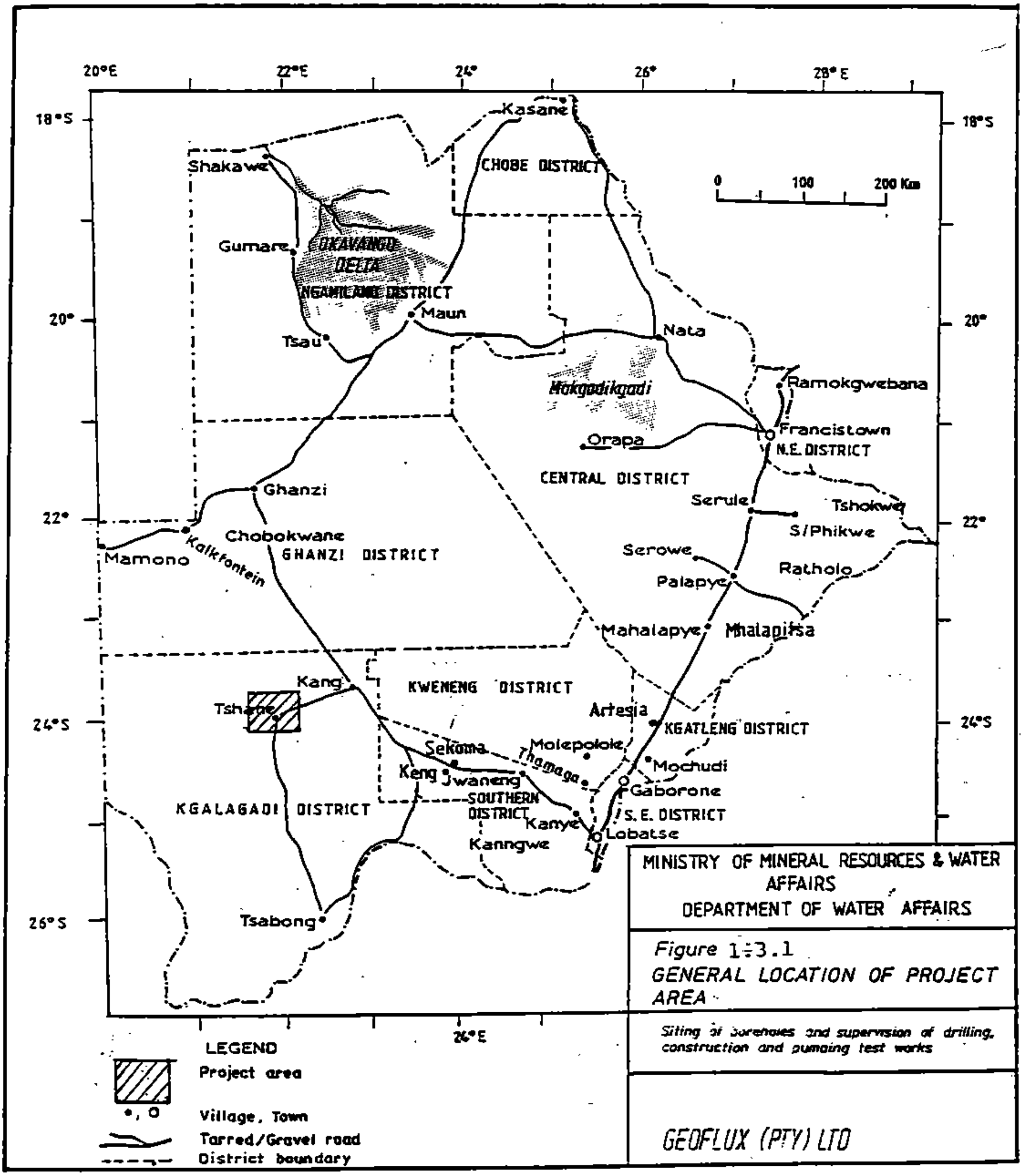

Figure 1.3.1
GENERAL LOCATION OF PROJECT AREA

1.3.3 Annual Rainfall

Rainfall in the project area is seasonal and mainly starts from October to April. Figure 1.3.2 shows plots of total annual rainfall for Tshane, Lehututu and Kang for the period 1964 to 1992. The long term average annual rainfall is 300 mm.

1.3.4 Population and Water Demand

According to the 1991 census (Population of towns, villages and localities, Central Statistics report, 1991) the combined population of Tshane, Lehututu, Hukuntsi and Lokgwabe was 5811. Projections for the combined population growth for the four villages are shown on table 1.3.1.

The projected water demand for the four villages for the year 2011 is 605 m^3/day. This is based on a per capita water consumption of 50 litres.

Table 1.3.1 Figures on Estimated Combined Population Growth of the Four Villages and their Combined Water Demand

YEAR	*1991	1996	2001	2011
Official combined population projection	5811	6904	8258	12100
Combined water demand (m^3/day)	290	345	413	605

*1991 enumerated population

Tshane village is currently supplied with water from one borehole (official number unknown) next to the police station. This borehole does not meet the water demand of the village, which sometimes results in instances whereby there will be no water in the village for several days (3-4 days). Villagers augment the short fall in water supply by getting water from hand-dug wells in the pan. Three other boreholes (6457, 6482 and 6484) with fresh water have been equipped for the village's supply once the construction of a pipe in the village is completed. These three boreholes are also intended to supply water to two settlements of Shwape, 3.0 km to the east, and Ngwaborwa, 2.5 km to the south. Water for livestock watering is from wells dug in the pan.

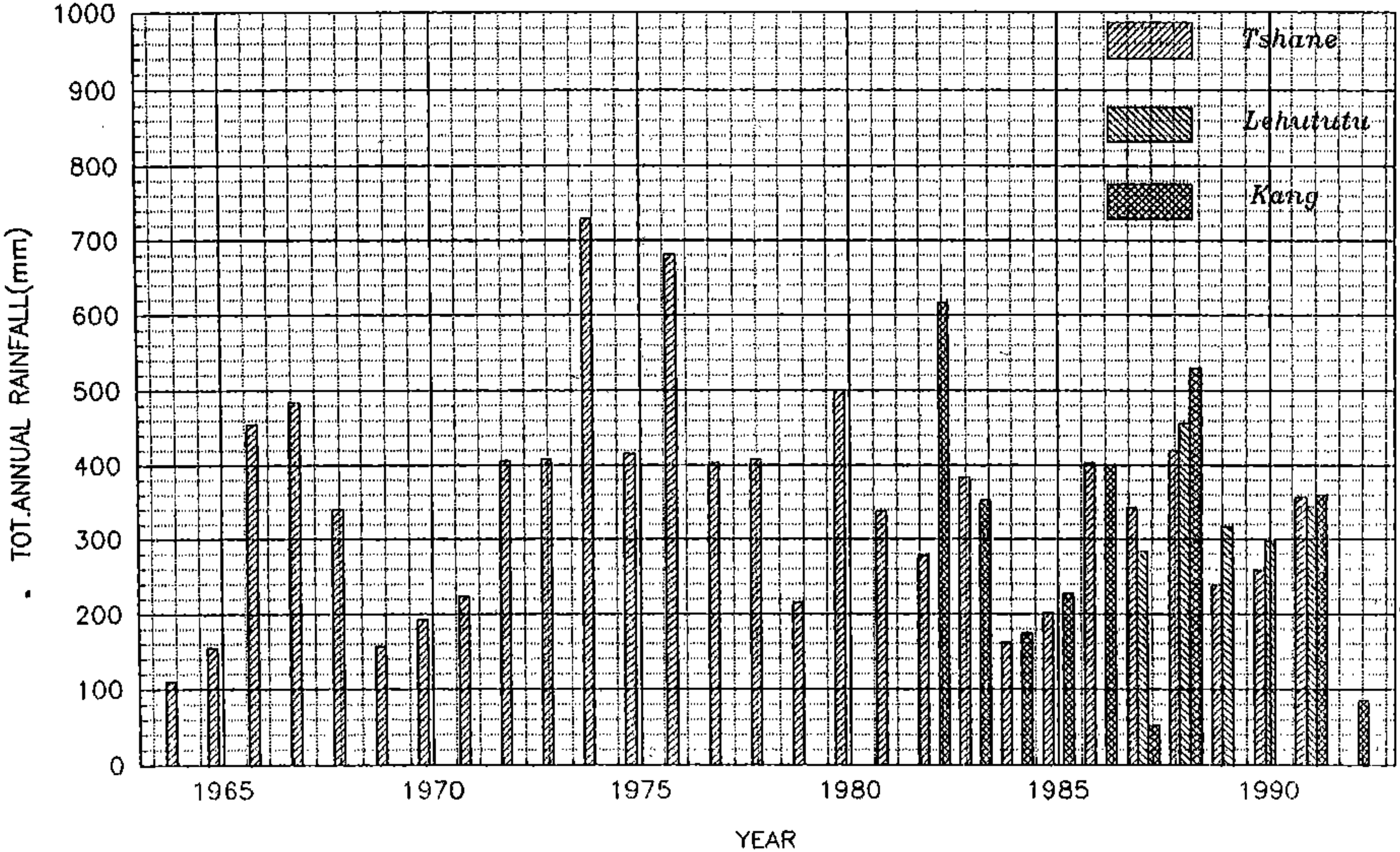

Figure 1.3.2 Annual Rainfall Totals (mm) for Tshane, Lehututu and Kang

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Hukuntsi village is supplied by five (5) boreholes (5284, 5283, 5846, 4516, and a borehole with unknown official number next to borehole 2922). The water from these boreholes is inadequate to meet the present water demand and hence additional water is piped from Lehututu boreholes. The combined water supply from the village boreholes and that piped from Lehututu is still inadequate to meet the water demand for Hukuntsi. Water for livestock drinking is obtained from hand-dug wells in the pan.

Water supply for Lehututu village is from three (3) boreholes (5947, 5948, 6046). These boreholes do not meet the water demand for Lehututu because they also supply Hukuntsi, and other nearby settlements such as Zutsha, Gukhwa, Okhwi, Make and Monong. Livestock is watered from hand-dug wells in the pan which have fresh water.

Lokgwabe village is supplied with water from borehole 5448, pumping at 1.0 m^3/h. This borehole meets the present water demand for the village but the supply is not adequate for any future major developments to be undertaken in the village. Livestock is watered from hand-dug wells in the pan which have fresh water.

1.3.5 Infrastructure

The infrastructure of the four villages (Tshane, Hukuntsi, Lehututu and Lokgwabe) is discussed separately below.

Tshane has tribal administration offices (which also house local police), police station, primary school, Meteorological Services Department Office, Health post, agricultural offices, Post Office which is still under construction, and an adult education centre. There are additional planned development projects which are currently hampered by shortage of water. These include building of a prison, improvement of show grounds, vegetable garden, construction of tarred roads linking Tshane, Lehututu and Hukuntsi, and construction of VIP guest houses.

Infrastructure in Hukuntsi comprises agricultural offices, tribal administration offices (which house local police), Department of Information and Broadcasting Office, Food Resources Department Office, Post Office, Land Board Office, Revenue Office, Education Office, Wildlife Department Office, Tirelo Sechaba Department Office, National Registration Office, RAD hostels, two primary schools, a Community Junior Secondary School, Council Water Unit office, Department of Water Affairs Office, and C.T.O depot. There are also several planned development projects which are hampered by water shortage. These include construction of a hospital, construction of a Rural Administration Centre, extension of Wildlife Department Offices, a tannery, construction of tarred roads, development of the existing airstrip, and development of an industrial area in the village.

Infrastructure in Lehututu consists of agricultural offices, tribal administration office, social welfare office, RAD hostels, Post Office, primary school, and a health post. Other planned development projects that are hampered by water shortage include building of a clinic, building of a day care centre, and building a brigade.

The village of Lokgwabe has a health post, tribal administration office (which also house local police), a primary school, agricultural offices, and a postal agency. There are also other planned development projects that are currently hampered by water shortage and these include building of a Red Cross Office, building of a Community Hall, building of a Post Office, building of a Public Library, and construction of houses for council employees.

1.3.6 Economic Activity

The major economic activity in the four (4) villages is mainly pastoral farming and subsistence arable farming.

1.4 Geology

The geology of the project are comprises rocks of the Karoo Supergroup that are underlain by variable thicknesses of Kalahari beds. Lithological logs of boreholes in the project area are shown on Table 1.4.1.

Table 1.4.1 Drill Hole Logs of Boreholes in the Project Area

BOREHOLE	DEPTH (m)	LITHOLOGY	COMMENTS
1505	41	0-15.24 sand with calcrete fragments 15.24-21.34 Calcretes and silcretes 21.34-41 Silcrete	Logged at GS by Geoflux
2649	107	0-3 Sand 3-9 Calcrete 9-40 Greenigh mudstone 40-107 Brown and grey mudstones	Logged at GS by Geoflux
2827	204	0-36 Gravel 36-136 Clay 136-204 Grey, brown and yellow mudstone	Logged at GS by Geoflux

BOREHOLE	DEPTH (m)	LITHOLOGY	COMMENTS
4237	191	0-9 Calcrete and silcrete 9-54 Mudstones 54-93 Greyish and reddish brown siltstones 93-191 Grey siltstone	Logged at GS by Geoflux
4267	120	0-9 Calcrete 9-66 Grey and reddish brown mudstone 66-93 Light grey siltstone 93-120 Reddish brown sandstone	Logged at GS by Geoflux
4430	196	0-6 Calcrete 6-9 Light brown sand 9-30 Light greyish clay 30-196 Greenish mudstones	Logged at GS by Geoflux
4433	104	0-104 Shale	Logged at GS by GS
5947	42	0-6 Sand and calcrete 6-20 Calcrete 20-31 Sand and clay 31-41 Sandstone 41-42 Shale and clay	Logged by driller
5968	87	0-6 Sand and calcrete 6-9 Sandstone 9-18 Clay and sandstone 18-87 Sandstone	Logged by driller
5948	25	0-3 Sand 3-6 Gravel 6-15 Clay with calcrete 15-18 Calcrete with sandstone 18-25 Sandstone	Logged by driller
6046	25	0-4 Sand and gravel 4-12 Sandstone 12-25 Clay and sandstone	Logged by driller
6088	25	0-3 Sand and gravel 3-6 Sand with shale 6-9 Shale with sandstone 9-25 Sandstone	Logged by driller
6160	422	0-21 Silcrete, calcrete and clay 21-219 Mudstone and Shale 219-422 Siltstone and mudstone	Logged by Geo Technical
6183	38	0-10 Sand and calcrete 10-27 Mudstone 27-38 Shaley sandstone	Logged by driller

BOREHOLE	DEPTH (m)	LITHOLOGY	COMMENTS
4492	40	0-3 Sand 3-40 Gravel and shale	Logged by driller
4516	89	0-20 Sandstone 20-30 Limestone 30-89 Shale	Logged by driller
4617	84	0-36 Calcrete and silcrete 36-84 Reddish brown mudstone	Logged at GS by Geoflux
5282	106	0-2 Brown sand 2-8 Calcrete and silcrete 8-106 Brown, grey to dark grey mudstone	Logged at GS by Geoflux
5448	108	0-6 Calcrete 6-32 Sandstone 32-36 Mudstone 36-108 Sandstone	Logged by driller
5793	50	0-1 Sand 1-10 Calcrete 10-25 Silcrete 25-39 Shale 39-50 Mudstone	Logged by driller
5846	42	0-3 Sand 3-9 Gravel 9-12 Calcrete 12-42 Mudstone	Logged by driller
5847	44	0-4 Sand 4-13 Calcrete and silcrete 13-20 Mudstone 20-44 Shale	Logged by driller
6187	38	0-6 Sand and gravel 6-18 Shale 18-38 Clay	Logged by driller
6457	122	0-10 Gravel 10-16 Shale 16-30 Sandstone 30-122 Shale and gravel	Logged by driller
6481	260	0-45 Sand, calcrete, silcrete and ferricrete 45-243 Clay and mudstone 243-260 Fine sandstone	Logged by DWA
6482	66	0-3 Sand 3-10 Calcrete and silcrete 10-66 Reddish brown, grey and greenish grey mudstone	Logged at GS by Geoflux

BOREHOLE	DEPTH (m)	LITHOLOGY	COMMENTS
6484	22	0-20 Sandstone 20-22 Shale	Logged by driller (DWA)
Z5523	67	0-30 Silcrete 30-48 Reddish brown mudstone 48-67 Greenish grey sand	Logged at GS by Geoflux
4367	150	0-3 Ferricrete 3-15 Reddish brown mudstone 15-150 Reddish sandstone	Logged at GS by Geoflux
4398	81	0-12 No samples 12-18 Calcrete 18-48 Greenish mudstone 48-81 Reddish brown mudstone	Logged at GS by Geoflux
Z6132	57	0-3 Grey sand 3-48 fine grained stratifined sand 48-57 Pinkish semi-consolidate sand	Logged at GS by Geoflux
4220	120	0-6 Gravel 0-21 Calcrete 21-36 Semi-consolidated sand 36-48 Weathered dolerite 48-120 Dolerite	Logged at GS by Geoflux
1521	33,53	0-15.24 Calcrete and silcrete gravel 15.24-33.53 Silcrete	Logged at GS by Geoflux
1513	27,43	0-18.2 Silcrete 18.2-27.43 Brownish mudstone	Logged at GS by Geoflux
6377	150?	0-21 Sand 21-108 Calcrete + silcrete 108-124 Mudstone 124-144 Pink sandstone 144-? Dolerite	Logged at GS by Geoflux
4933	181	0-6 Brown sand 6-21 Calcrete and silcrete 21-72 Brown clay 72-87 Brown mudstone 87-171 Grey mudstone	Logged at GS by Geoflux

1.4.1. Karoo Supergroup

The project area is situated along the margins of the Western Central Kalahari and Southwest sub basins of the Karoo Supergroup. The lithostratigraphy of the Karoo Supergroup in Botswana is described in detail by Smith (1984). Rocks of the Karoo Supergroup have been noted to show varied facies and depositional patterns (Smith, 1984). The generalised Karoo stratigraphic successions for the project area is shown on Table 1.4.2.

Dwyka Group

The lower most unit of the Karoo in the area is the Dukwi Formation of the Dwyka Group. It comprises tillites, pebbly mudstones, pebbly siltstones and diamictites.

Ecca Group

The Dukwi Formation is unconformably overlain by the Bori Formation of the Ecca Group. The Bori Formation comprises dark grey or black shales and siltstones. It was deposited in troughs in the palaeo-relief of the pre-Karoo basement (Smith, 1984) and is hence not systematically encountered everywhere. Its thickness varies considerably from a few meters to tens of meters.

Overlying the Bori Formation are the Kweneng and Boritse Formations comprising sandstones, siltstones, coals and carbonaceous mudstones. These formations were subdivided by Williamson (in prep) into upper, middle and low Mmamabula Formations. The thickness of these formations is variable depending on the structural location, with greater thickness in grabens with a large throw on the fault/ridge plane (BRGM, 1991).

The Boritse Formation is overlain by the Kwetla Formation which comprises non-carbonaceous mudstones and siltstones.

Lebung Group

The Mosolotsane Formation (formerly transition or red beds (Green, 1966) essentially consists of medium to fine grained red mudstone often with conglomerate bases. This formation lies unconformably over the Kwetla Formation and is conformably overlain by the Ntane Sandstone Formation. Smith (1984) envisages a depositional environment during the Mosolotsane Formation times in which terrestrial fluviatile conditions were prevalent or rainfall was seasonal.

The Ntane Sandstone Formation essentially comprise a uniform sequence of reddish to pinkish (often with pale to white colorations) medium to fine grained, well sorted, poorly cemented and friable sandstone. The formation is overlain unconformably by Kalahari Beds. The sandstone is thought to be aeolian, though fluviatile activities have been postulated (Smith, 1984).

Table 1.4.2 **Generalised Stratigraphic Succession of the Karoo Supergroup**

LITHOLOGY	FORMATION	DIVISION	AGE
Topsoil, sands, clays, calcretes, silcretes, gravels, sandstones		Kalahari	Cretaceous to Recent
---UNCONFORMITY---			
Fine grained aeolian sandstones	*Ntane	Karoo Supergroup	Triassic to Jurassic
Fluvial red sandstones	*Mosolotsane		
---UNCONFORMITY---			
Non-carbonaceous mudstones and siltstones	**Kwetla	Karoo Supergroup	Triassic to Jurassic
Carbonaceous mudstones, coals, siltstones and medium to coarse sandstones	**Boritse		
Medium to coarse felspathic sandstones with minor lenses of grey siltstones and mudstones	**Kweneng		Triassic to Jurassic
Shales, siltstones	**Bori		
---UNCONFORMITY---			
Tillites, pebbly mudstones, pebbly siltstones, diamictites	***Dukwi	Karoo Supergroup	Triassic to Jurassic
Intrusives (Dolerites)			Post to intra Karoo

* Lebung Group
** Ecca Group
*** Dwyka Group

1.4.2 Kalahari Beds

Kalahari beds comprise a sequence of predominantly terrestrial sediments of cretaceous to Recent age. The nature of the Kalahari deposits varies from aeolian to fluvio-deltaic and lacustrine indicating deposition to have been through several extreme climatic cycles. Lithologies of the Kalahari beds comprise sandstones, silcretes, conglomerates, calcretised and silcretised sands, calcretes, lake limestones, clays, gravels, siltstones and aeolian sands. The thickness of the Kalahari beds in the project area is variable, ranges from 30 to 70 m, but thicknesses up to 100 m or more can be expected in localised areas.

1.4.3 Structural Setting of the Project Area

Structural features related to underlying bedrock discontinuities can be mapped from the regional aeromagnetic map of Botswana and airphoto interpretation map (Figure 1.4.1). It appears from the regional aeromagnetic trends and airphoto interpretation map and structure of the southern African region that four main groups of fault lineaments can be identified in the area of Tshane, Hukuntsi and Lehututu. These four lineament sets are defined as follows:

- east-west trending lineaments which are most probably related to the Zoetfontein Fault Zone.
- northerly trending Kalahari line which passes through Tshane and Lehututu is probably related to the north-south trending lineaments identified in the area.
- northeast-southwest trending lineaments.
- northwest-southeast trending lineaments which are in places filled by dolerite dykes.

1.5 Hydrogeology

1.5.1 Previous Work

Numerous boreholes (Figure 1.5.1) have been drilled by the Department of Water Affairs and individuals from 1960's to 1993 to meet both the water requirements for the four villages and livestock watering. A multitude of shallow hand-dug wells have been dug in the immediate vicinity of the large pans from which the villages are named. There is no technical documentation on the siting of the numerous boreholes in the area and hence the understanding of the groundwater occurrence in the area remains virtually not well understood.

Existing borehole information and that from hand-dug wells indicate the presence of shallow (<50 m) fresh water and shallow saline water aquifers and a deep (>80 m) saline water aquifer in the project area. The lateral extent and nature of the shallow aquifers are unknown. A summary of hydrogeological information of boreholes in the project area is shown on Table 1.5.1.

1.5.2 Groundwater Occurrence

There are potentially four main aquifer units, three of which belong to the Karoo Supergroup and one to the Kalahari beds, within a 20 km radius of the three project villages. The Karoo Supergroup aquifer units belong to the Lebung (Ntane) and Ecca (Kweneng and Boritse) Groups.

Aquifers of the Ecca Group are known, from previous studies throughout Botswana, to be complex and variable in lithology both vertically and laterally. In the project area there is a prevalence of interbedded mudstones, siltstones and sandstones with highly variable borehole yields (range from less than 1 m^3/h to 10 m^3/h). Groundwater occurs at depths generally exceeding 100 m below ground level and its storage and movement is controlled by secondary fractures and to a lesser extent by intergranular pore spaces within the grit and arkose horizons. Pumping test results of borehole 6481 (near Tshane) give transmissivity and specific capacity values of 1.4 m^2/day and 0.22 $m^3/h/m$ respectively (Table 1.5.2). The quality of water from the Ecca Group aquifer units within the project area is unsuitable for human consumption with TDS values exceeding 10000 mg/l. Based on results from previous drilling programmes within the project area, the Ecca Group aquifers will not be investigated in this study because of non-potable water problems.

Aquifers of the Lebung Group (Ntane Formation) are generally known throughout Botswana to have good groundwater potential. In the project area the Ntane sandstone appears to occur as an outlier bounded to the south by the Zoetfontein fault. There is not much hydrogeological information on this aquifer in the project area except for three boreholes (borehole 6374, 6376 and 6377) whose actual locations are not accurately known. Based on the drilling results of these three boreholes the Ntane sandstone aquifer will be investigated in this study. The three boreholes encountered water within sandstones at depths ranging from 87 to 130 m and gave airlift yields ranging from 2 to 13.5 m^3/h. The quality of the water in the three boreholes is suitable for human consumption with TDS values ranging from 1038 to 1400 mg/l. Groundwater in the Ntane sandstone aquifer occurs in primary interstitial pores but yields are enhanced by the presence of fractures.

SW of Tsane. 6374 + 6376 supposedly have accurate locations All LWF bhs.

Groundwater in the Kalahari beds occurs in the form of perched aquifers with unknown geometry (lateral and vertical extent) in the project area. Water strikes in the Kalahari aquifer(s) are generally at a depth less than 50 m below ground level (Table 1.5.1). Borehole yields are highly variable and range from less than 1 m^3/h to 5 m^3/h. Pumping test results of eight (8) shallow boreholes (near Tshane, Lehututu and Lokgwabe) give transmissivity values and specific capacities ranging from 1.1 to >100 m^2/day and 0.12 to 1.63 $m^3/h/m$ respectively at pumping rates ranging from 1.05 to 7.0 m^3/h Table 1.5.2). Based on the numerous boreholes and countless hand dug wells in the project area, there is generally fresh water (TDS less than 1500 mg/l) south of Lehututu and saline water to the north (Ohe, Monong, Make, Pepane Pans). Within the area of fresh water south of Lehututu there is potential for saline water to occur at greater depths where Kalahari beds are locally very thick. This phenomenon has been observed in other parts of Botswana where Kalahari aquifers are thick (>100 m) e.g Hainaveld area south of Maun. This study will delineate both the lateral and vertical extents of the fresh (potable) water zones within the perched Kalahari beds aquifer. The nature of the perched aquifer will also be studied in order to investigate whether it is laterally continuous or occurs locally in the vicinity of pans and dunes.

1.5.3 Hydrochemistry

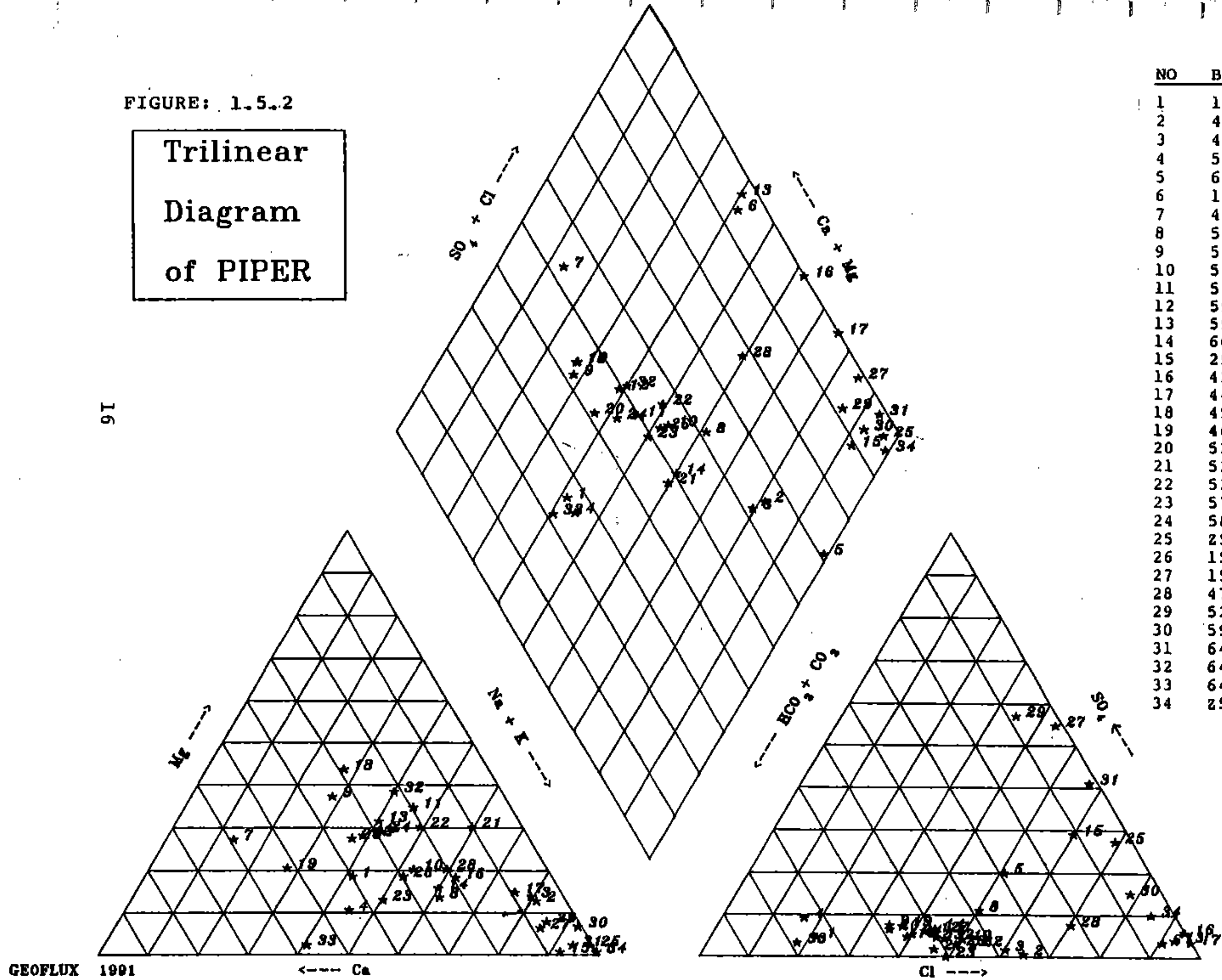
Existing hydrochemical data of boreholes in the project area show two main water types with no apparent lateral variation or areal distribution. Fresh water (TDS <1500 mg/l) is mainly associated with the shallow perched aquifer(s) south of Lehututu and around the pans of Tshane, Hukuntsi and Lokgwabe. This water is mainly of a $CaMg-HCO_3$ type (Figure 1.5.2) with elevated amounts of sodium, chloride and sulphate. The other water type is mainly saline (TDS >3000 mg/l and upto 100000 mg/l) and associated with the deep Karoo aquifer(s) and the shallow perched aquifer(s) north of Lehututu. These saline waters are mainly of a Na-Cl, SO_4 type (Figure 1.5.2). Hydrochemical data is also shown on table 1.5.3.

The fresh low TDS water from the shallow perched aquifer(s) is generally suitable for human consumption with fluoride and nitrate levels below the World Health Organisation's maximum permissible limits for drinking water.

Groundwater from the deep Karoo aquifer(s) is unsuitable for human consumption with TDS in excess of 3000 mg/l.

FIGURE: 1.5.2

Trilinear Diagram of PIPER



NO	BH	LOCATION
1	1521	Lokgwabe
2	4292	Lokgwabe
3	4267	Hukuntsi
4	5448	Lekgwabe
5	6377	Lokgware
6	1505	Lehututu
7	499	Lehututu
8	5497	Lehututu
9	5911	Lehututu
10	5947	Lehututu
11	5948	Lehututu
12	5967	Lehututu
13	5968	Lehututu
14	6046	Tshane
15	2920	Hukuntsi
16	4220	Hukuntsi
17	4433	Hukuntsi
18	4516	Hukuntsi
19	4617	Hukuntsi
20	5283	Hukuntsi
21	5284	Hukuntsi
22	5285	Hukuntsi
23	5793	Hukuntsi
24	5846	Hukuntsi
25	Z5316	Hukuntsi
26	1513	Tshane
27	1514	Tshane
28	473	Tshane
29	529	Tshane
30	5999	Tshane
31	6481	Tshane
32	6482	Tshane
33	6484	Tshane
34	Z5523	Tshane

check on database

Table 1.5.1 Summarised Borehole Information of Project Area

BH NO.	DEPTH (m)	WATER STRIKE (m)	SWL (m)	Q (m^3/h) Airlift	TDS (mg/l)
5448	108	33 42	10.0	6	500
6484	22	11	10.24	8	888
6481	260	246- 260	85.33	6-11	44010
6160	422	420	122	25	17580
6457	122	14	10.2	1	572
6482	66	21	12	6	584
2649	189 185.3	156	157	2.4	629
5282	106	Dry	-	-	-
5793	50	27	20.21	<1	618
5846	42	12	10	3	672
2922	33 33.57	10	10	2.00	
5847	44	32	13.1	?	
2827	230	5	5	2.4	612
4492	40	21	14.68	?	543
2692					
4617	86.6	31 42	30.9	2	526
2649	185	4.6	5.0	1.0	853
4516	89	6 51	6	2.4	608
4594	230				
4433	104	70 77	13.45		110898 38320
4267	122	100	-		14650
4430	198	88 196	100		Very salty
6046	25	18	13.34	1	868
Z4562	61	30	30	?	-
6183	38	28	18.8	3	516
6187	38	Dry	-	-	-

BH NO.	DEPTH (m)	WATER STRIKE (m)	SWL (m)	Q (m^3/h) Airlift	TDS (mg/l)
5948	25	18 22	22.14	2	918
5947	42	16 36	12.6	2 8	1058 968
5968	87	25 34	17.36	2 10	15344
6088	25	18	13.4	7	802
4237	91	60 80	13.75	?	-
1505	41	27	13.2	?	5660
6588	370	127 289 367	85.3	1.5 12	11300
4937	250	95	?	very low	35386
4936	250	136	?	very low	-
4935	250	160	?	very low	-
4934	230	157	-	very low	-
4933	181	118	-	very low	-
5127	23	18	14.68	0.4	380
6589	432	dry	-	-	-
6559	-	-	-	-	-
5128	21	4 10 15	3.3	3	-
4938	250	95	?	very low	-
6339	388.5	56 116 375	95.54	15	20722
6086	-	-	-	-	-
4398	91	35 55 89	50.0	?	10430
4515	89	6 51	6.0	2.4	-
5283	46	6 18 31	?	3.5	532

BH NO.	DEPTH (m)	WATER STRIKE (m)	SWL (m)	Q (m^3/h) Airlift	TDS (mg/l)
5284	75	10	?	1.0	812
5285	28	15	?	5.0	700
1521	34	23	12.2	2.3 (9 hrs)	463
4367	-	-	-	-	1364
6377	150	120	?	2.5	1400
6374	126	87 114	98.06	0.5 2.0	1118
6376	150	108 132	101.03	1.5 13.5	10.38
3741	83	-	14.3	1.7	900
499	- 43.59	-	-	-	844
2920	-	-	-	-	13728
4220	-	-	-	-	52742
Z6132	108	14 54	90	2.5	1846
Z5265	126	?	84	?	39308
Z5316	147	?	80	?	27628
1513	48	dry	-	-	1004
1514	180.8	174	?	?	10728
473	108	24 35	22.86	3	1168
5911	-	-	-	-	708
2915	-	-	-	-	532
Z5523	-	-	-	-	21108
5803	400	390	190	?	-
5497	-	-	-	-	996
5967	50	23	15.47	2.0	618

Table 1.5.2 Summary of Test Pumping Results from Existing Boreholes

BH NO.	LOCALITY	SWL (m)	PUMPING TIME (hrs)	AQUIFER	DISCHARGE (m^3/h)	DRAWDOWN (m)	Q/S AFTER 3hrs ($m^3/h/m$)	TRANSMISSIVITY		COMMENTS
								PUMPING	RECOVERY	
6484	Tshane	10.24	48	Shallow perched Sand	6.0	4.74	1.63	15.5	7.32	Good test data, constant Q
6481	Tshane	85.66	28	Karoo	9.5	44.12	0.22	1.44	1.35	Good test data with constant Q
6482	Tshane	12.57	43	Shallow perched Karoo/ Kalahari?	3.0	37.62 (suction)	1.60	132 0.66*	0.55	Yield constant throughout test
6046	Lehututu	13.34	48	Shallow perched Karoo/ Kalahari?	1.05	0.97	1.30	10.5 32.9*	8.0	Yield constant throughout test
5948	Lehututu	12.14	48	Shallow Karoo/ Kalahari?	1.30	0.59	2.53	22	15.4	Yield decreased from 1.7 to 1.03 m^3/h
6088	Lehututu	13.40	48	Shallow Karoo/ Kalahari?	4.03	5.82	1.25	5.9 7.7*	5.4	Yield constant but data showing step type behaviour
5968	Lehututu	17.67	48	Shallow Kalahari/ *Karoo	7.0	9.28	0.96	25.6	19.2	Yield decreased from 6.7 to 4.5 m^3/h
5947	Lehututu	12.60	48	Kalahari and *Karoo	6.7	1.08	10.0	86.5	116.3	Yield decreased from 6.0 to 3.3 m^3/h
5448	Lokgwabe	10.0	48	Shallow Kalahari/ Karoo??	6.0	69.29	0.12	1.1	0.22	

Table 1.5.3 <u>Hydrochemical Data of Boreholes in the Project Area</u>

BH NO	SAMPLE DATE	pH	EC (μs/cm)	TDS (mg/l)	ANIONS (mg/l)						CATIONS (mg/l)			
					HCO_3	CO_3	Cl	SO_4	NO_3	F	Ca	Mg	Na	K
1521	12/03/91	7.8	686	463	285	19	28	14	35	1.0	57	16	50	30
4292	31/05/87	7.7	3705	2371	685	0	734	9	1	1.6	38	50	580	27
4367	31/05/87	7.5	2388	1364	441	0	404	15	1	0.74	26	34	350	26
5448	07/06/93	7.8	767	500	302	0	23	30	29	1.58	61	9	68	3
6377	07/06/93	8.4	2450	1400	390	0	56	389	211	3.28	1	2	510	20
1505	07/06/93	7.6	-	5660	305	0	2755	144	0	2.0	509	301	800	16
499	02/11/88	8.0	1090	844	366	0	111	38	176	0.56	164	46	40	5
5497	20/11/88	7.6	1544	996	366	17	253	83	43	1.15	84	28	230	11
5911	19/05/88	7.3	999	708	356	0	62	37	106	1.08	70	46	59	11
5947	07/06/93	7.6	1494	968	398	0	224	29	5	2.00	79	37	175	8
5948	07/06/93	7.9	1353	918	417	0	175	31	7	1.58	50	54	129	6
5967	14/11/88	7.7	930	618	373	0	85	35	17	1.30	75	39	92	16
5968	31/01/90	7.5	15463	15344	343	0	5840	346	3	0.19	1048	712	1700	35
6046	07/06/93	7.5	1465	868	443	0	185	47	7	1.58	72	29	200	10
2920	12/03/84	9.3	15600	13728	1348	398	4255	2837	7	4.00	320	20	4600	38
4220	24/10/83	7.3	69600	52742	102	0	30283	2604	-	1.45	3200	1840	11600	200
4433	18/12/84	6.9	103000	110898	195	0	63048	3200	-	-	3300	3240	31000	200
4516	16/06/93	7.5	901	608	302	0	47	20	13	1.58	51	46	50	8
4617	02/11/88	8.1	700	526	231	20	29	24	10	0.82	87	21	50	5
5283	16/06/93	7.6	846	532	290	24	72	26	5	1.58	65	31	75	4
5284	14/03/86	7.6	1175	812	337	0	104	9	12	1.40	16	29	100	14

BH NO	SAMPLE DATE	pH	EC (µs/cm)	TDS (mg/l)	ANIONS (mg/l)						CATIONS (mg/l)			
					HCO_3	CO_3	Cl	SO_4	NO_3	F	Ca	Mg	Na	K
5285	30/03/86	8.1	1161	700	280	0	83	14	20	1.20	57	33	98	6
5793	08/05/88	7.9	891	618	305	0	145	0	4	-	63	14	96	5
5846	16/06/93	7.8	895	590	298	0	108	23	3	1.58	54	33	87	5
Z5316	18/06/86	7.4	41234	27388	878	0	10210	5500	-	0.58	68	170	13500	28
1513	04/05/73	7.3	1480	1004	416	0	225	20	-	0.65	92	35	180	6
1514	04/05/73	7.8	-	10728	143	0	2416	4130	-	5.00	267	123	3090	15
473	07/06/93	7.7	1800	1168	194	14	266	52	161	1.58	60	37	200	6
529	07/06/93	7.7	21900	1168	229	25	550	1238	0	12	62	46	928	30
6481	01/09/89	8.3	21900	28040	227	12	6321	6171	-	-	230	80	6060	40
6482	14/12/89	7.6	867	584	243	14	50	17	14	0.85	36	39	74	5
6484	01/12/89	7.4	888	598	302	9	40	10	-	0.44	72	2	56	5
Z5523	02/05/87	-	38121	21108	841	0	8662	1400	-	0.58	4	36	8520	5
6088	05/09/88	7.1	1128	802	462	116	49	65	0.74	15.0	74	24	155	7.4

2.0 GENERAL PROJECT STRATEGY

The objectives of the project are detailed under section 1.2. However these can be summarised and reviewed as follows:

i) Definition/delineation of the perched aquifer:

Nature of the perched aquifer:

- areal extent
- lithological environment
- thickness

ii) Assessment of groundwater quality.

iii) Quantification of the groundwater resources.

iv) The most efficient combination of geophysical methods to use in the delineation of the perched aquifer.

v) The expected recharge to the perched aquifer.

vi) Drilling of boreholes to adequately meet the water needs of the village of Lehututu, Tshane and Hukuntsi.

General Approach

A wealth of information from previous studies on borehole positions, lithological logs, water levels, water quality and yield, aquifer types has been gathered in this phase. This information has been collated and synthesised to optimise technical benefit. The reliability of the data base is highly variable but synthesis and evaluation for correctness and accuracy, particularly with respect to Drillers logs will continue. The positions or distribution of boreholes and associated information is of critical importance for the delineation of the vertical and lateral extent of the perched aquifer and the quantification of groundwater resources. The positions and lithologic names are however usually highly inaccurate and will continue to be addressed in the framework of this study. The fact that the aquifer is perched and its thickness is unknown warrants good heighting control for the stratigraphic and lithologic correlation and vertical delineation of the geology and the aquifer. Current water levels and verifications of water quality through sampling will also be undertaken in the process. Thus an inception and desk study with a field inventory and verification were essential for the utilization of existing information, upgrading of past work as well as for effective interpretation.

Geophysical methods will be adapted to the different geological environments characteristic of the Kalahari and Ntane Sandstone aquifers as well as having a high capability of detecting a shallow perched aquifer.

Past village water supply projects have generally followed a conventional siting approach suitable for fractured geological environments where water salinity is not a problem, such as in eastern Botswana. Siting of boreholes for village water supply projects has invariably focused on drilling just enough boreholes to meet the required water demand.

Water supply to villages far away (western Botswana) from these relatively simpler geological and hydrogeological environments call for a totally different approach as the focus is on three distinct characteristics, mainly, the Kalahari beds, perched aquifers, and salinity. Application of conventional approaches has so far led to unsuccessful resolution of water supply problems to these three villages. This has led to expensive and recurrent geophysical and drilling investigations.

The area being investigated lends itself to an approach that will not only focus on drilling of boreholes solely for water supply to the three villages but requires proper lateral and vertical delineation of a potable water source (shallow and perched aquifers). This would allow for optimisation of borehole positioning for long term water supply. Proper delineation of the aquifer geometry requires a multitude of points which can only be achieved cost effectively by putting more emphasis on geophysical investigations than drilling. The geophysical programme must however be adequate in quantity and technique. This calls for a major departure from conventional village water supply siting strategies. This involves use of geophysical techniques with high diagnostic capabilities and applications of several methods for enhanced and corroborated interpretation. This invariably facilitates effective decision making and resolution of problems.

The siting of project boreholes should after evaluation of all existing information and geophysical investigations satisfy as a first priority, the water supply situation for the three villages but will secondarily also be positioned so as to provide hydrogeological information where it is lacking.

Water yielding project boreholes will be test pumped together with some existing ones with inadequate or poor borehole performance data. Existing boreholes proximal to a pumping test site will serve as observation boreholes. This will collectively enhance information on aquifer parameters for quantification of groundwater resources.

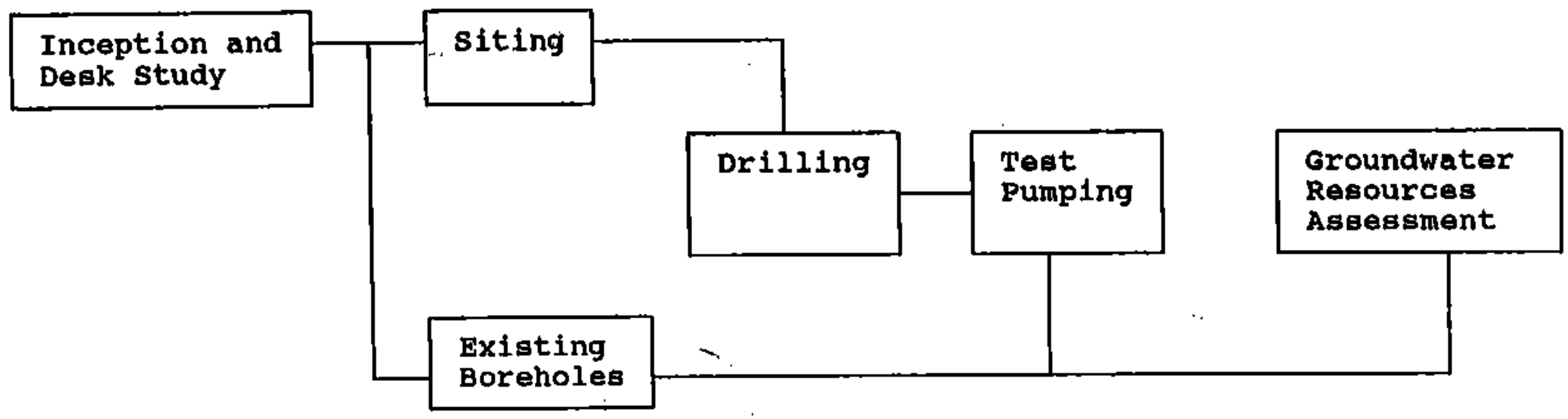
Recharge to the aquifers in the area will be assessed qualitatively using different techniques (climatology and chloride mass balance).

Fig 2.1.1 shows the flow of activities.

Fig 2.1.1

PROJECT STRATEGY

Flow of Activities



3.0 PLAN OF OPERATION

3.1 Inception Study

The overall objective is to compile and interpret all relevant data in order to gain a better understanding of the regional and local geological and hydrogeological framework which can be used to refine the geophysical and hydrogeological approaches adopted for the project.

The inception study was carried out according to the following tasks:

3.1.1 Archive Inventory

This consisted of:

- a review of all existing reports and analyses of all available data, borehole records and information relevant to the geology and hydrogeology of the investigation area. The data and reports were obtained from the Geological Survey Department and Department of Water Affairs.

- an evaluation of all existing data for the investigation area including the logging of existing cores and sludge samples. The data was obtained from the Geological Survey Department and Department of Water Affairs. The borehole data mainly comprised drilling information, water chemistry analyses and pumping test records.

  This phase was used to collect topographical maps, aerial photographs and satellite images required, mainly from the Department of Surveys and Lands.

3.1.2 Reconnaissance and Field Inventory

A field census of existing boreholes and water supply situation were carried out in the investigation area. The main tasks of the field inventory included the following:

- investigation and evaluation of the existing water supply system and an assessment of the water shortage problems resulting from the system. Village authorities were interviewed on the present supply situation, anticipated future water demand and presence of existing boreholes and locations of hand dug wells.

- plot all existing boreholes and hand dug wells on topographical maps and ascertain their status (i.e pumping or abandoned).

It was not possible to carryout some field measurements of water levels, electrical conductivity (EC), pH, temperature and total dissolved solids (TDS) as well as collection of water samples from all existing boreholes and hand-dug wells for full chemical analyses because of the time constraints in this phase.

3.1.3 Study and Interpretation of Airphotos and Satellite Imagery

The aims of the detailed airphoto interpretation and where available satellite imagery interpretation are:

- to accurately locate structural features such as dykes, lineaments, faults, fracture zones, potential recharge areas and other hydrogeologically significant features, which may be potentially the most promising areas for groundwater occurrence and/or exploitation.

- to improve the current knowledge of the geology, structural setting and geomorphology of the investigation area.

- to draw up/produce a base map and a geological and structural map both at a scale of 1:50 000. The base map was produced from aerial photographs and contains coordinates, rivers, valleys, pans, roads, tracks, villages, settlements, district boundaries, trigonometrical beacons/bench marks, centre points of the aerial photographs, etc. Geological and structural maps are based on existing updated regional mapping of the surface geology by the Department of Geological Survey, reconnaissance aeromagnetic survey sheets and (Reeves, 1978 Interpretation Aeromagnetic Survey; scale 1:250 000) and field checks.

3.1.4 Reprocessing/Interpretation of Available Aeromagnetic Data

Reprocessing of aeromagnetic data is considered unnecessary because the target environment is the shallow perched aquifer. This would have been an unnecessary expense to the client.

3.2 Geophysical Investigations

3.2.1 Delineation of Kalahari Beds Perched Aquifer

In order to delineate the Kalahari Beds perched aquifer and establish its geometry, the following geological and hydrogeological aspects must be understood:

(i) Vertical extent and hydrostratigraphy
(ii) Lateral/areal extent

3.2.1.1 Vertical Extent and Hydrostratigraphy

Geological/Hydrogeological Aspects

The vertical profile or hydrostratigraphy which requires delineation comprises the following:

- unconsolidated Kalahari sands.
- confining layers such as clay layers or aquitards.
- fresh water lenses
- saline water lenses
- associated calcretes and gravels
- base of Kalahari or bedrock interphase.

Geophysical Applications

Geophysical techniques will aim at discriminating between the various geological and hydrogeological features. The key application will be in mapping interfaces characterised by resistivity contrasts. TDEM has better vertical and lateral resolution in this respect than other surface electrical and electromagnetic techniques. TDEM has also proven effective for mapping interfaces of freshwater and saltwater in aquifer surveys. Numerous successful tests have been documented worldwide in recent years and the DGS has also undertaken trials over the same area (Hukuntsi area) with very positive results.

Despite the relatively high resolution capabilities of transient soundings in relation to other sounding techniques the problem of equivalence still remains when it comes to interpretation. As the question of resolving the hydrostratigraphy is fundamental in providing effective solutions of supplying potable water through this project, the confidence level of addressing equivalence problems can only be raised through corroborative quantitative interpretations of sounding methods.

It is to this end that three sounding techniques be applied: Transient soundings, d.c. resistivity sound (VES, and Frequency soundings. The transient sounding method (TDEM) whose high resolution capabilities and sensitivity toward conductive layers will be augmented by the d.c. resistivity technique (VES) which is most effective with respect to resistive layers. The problem of contact electrodes associated with VES will be further covered by the joint use of frequency soundings. The proposed three (3) soundings techniques do not constitute duplication but provide corroboration in the inevitable problem of equivalence. Hence, where results from different techniques echo the same resistivities and thicknesses, this adds certainty in interpretation, and where one method has limitations in resolution, another compensates.

The proposed geophysical approach together with borehole logs and controlled or limited drilling should provide an effective solution to the delineation of the potable water resources. This in Geoflux's view is the only way of improving on past attempts to resolve the problem of supplying potable water to these three villages.

Field Application and Equipment

Sounding methods will be carried out at all boreholes and wells with useful geological and hydrogeological information in the villages of Hukuntsi, Lehututu and Tshane as well as in the area targeted for investigation, Fig 3.2.1 (map pocket).

A grid will also be established to facilitate an approach that develops from a place of known conditions (vis-a-vis the perched aquifer) to quantification of its extent vertically and laterally. The three sounding methods will be carried out along the grid profiles at 1 km intervals.

Transient soundings will be performed using a Protem receiver and a TEM 47 transmitter. VES will be performed with the ABEM terrameter and booster while the frequency soundings will be carried out with the Apex Max-Min I.

3.2.1.1 Lateral/Areal Extent

The conductivity of soils and rock strata are influenced by factors such as water content, dissolved solids in groundwater and clay content of soils and rocks. Most of the factors are closely associated with the groundwater environment.

Mapping of changes in apparent conductivities laterally would in conjunction with the geoelectric profiles of the sounding methods and borehole information assist in the 3-D delineation of the perched aquifer.

Time domain electromagnetic profiling will be performed on the entire grid as laid out in Fig 3.2.1 to enable contouring of apparent conductivities.

3.2.2 Ntane Shallow Aquifer

The Ntane sandstone formation of the Karoo Supergroup is expected in the south-eastern part of the target area (Fig 3.2.1). The potential for a shallow fresh aquifer will be investigated in this area.

The target structures are:

(i) Secondary structures (fractures and faults)

(ii) Primary intergranular permeability

Geophysical Applications

Secondary structures have been identified in the south-eastern part of the target area using areal photographs. These will be the prime targets for siting of boreholes. Coincident primary intergranular permeability will also be investigated. Soundings as applied in the Kalahari perched aquifer will be used to study the Karoo layering and shallow aquifer potential. However, only the Transient soundings will be performed in this sedimentary environment as delineation is not as critical as in the Kalahari perched aquifers. Dolerite dykes area also expected in the area and do not constitute ideal target for groundwater potential. These however have to be identified within the area being investigated and be avoided during drilling.

Field Applications and Equipment

The grid system has been extended to the south-east of the project area to cover the targets identified through the study of areal photographs (line 8.1E to 18.E, Fig 3.2.1). The structural trends are NW-SE and SW-SE. Time domain electromagnetic surveying will be carried out in the slingram mode (profiling) at right angles to these structural directions using a PROTEM system at 20 m station spacing.

Transient soundings will be continued into this area at 1 km intervals to determine possible continuity of Kalahari aquifer as well as to study the Karoo potential and hydrostratigraphy.

Magnetic profiling will also be carried out only over the south-eastern area along the NW-SE and SW-NE directions. This is to identify possible dolerite dykes trending NW-SE and faults trending NW-SE SW-NE.

The grid will be positioned using GPS coordination to ensure optimal orientation and positioning with respect to pans and photogeological structures. All survey points and grid positions will thus be coordinated to achieve accuracy.

Table 3.2.1a and b summarise the quantities for the proposed geophysical program.

This program is considered to have a high diagnostic potential for resolution and identification of potable groundwater in the Kalahari aquifer and shallow Ntane sandstone formation.

The cost also offers a cost benefit to the alternative of intensified exploratory drilling.

Table 3.2.1a **Proposed Geophysical Quantities and Methods**

GEOLOGICAL/ HYDROGEOLOGICAL ENVIRONMENT	PURPOSE	METHOD	QUANTITIES		CALIBRATION SOUNDINGS	TOTALS	
			PROFILING (line-kms)	SOUNDINGS		PROFILING	SOUNDINGS
Kalahari	Delineation of vertical profile and hydrostratigraphy	i) Transient-soundings (T-S) ii) VES iii) Frequency soundings (FS)		203 130 203	26 10 26		229 140 229
	Delineation of areal extent of perched aquifer	i) TDEM-slingram mode	203			203	
Ntane Sandstone Formation + possible extension of Kalahari perched aquifer	Identification of secondary fractures + possible primary intergranular permeably in Ntane. Delineation of vertical and lateral extent of Kalahari aquifer if extending into this area.	i) Transient-soundings (T-S) ii) TDEM-slingram mode iii) Magnetics	 101 101	101		 101 101	101
				TOTALS	MAG	101	
					TDEM	304	
					TS		330
					VES		140
					FS		229

Fig 3.2.1b **Grid Profiles**

GEOLOGICAL ENVIRONMENT	PROFILE NUMBER	LINE-KMS
Kalahari	12.9W	28.2
	6.8W	34.7
	00BL (N-S)	35.0
	8.1E	13.5
	10.S	21.0
	00BL (W-E)	24.0
	6.8N	24.0
	17.5N	23.0
	Sub-Total	203.4
Ntane + Kalahari	8.1E	17.0
	13.0E	17.0
	18.1E	17.0
	10.S	10.0
	3.5S	10.0
	00BL (W-E)	10.0
	3.3N	10.0
	6.8N	10.0
	Sub-Total	101.0
	TOTAL	304.4

3.2.3 Siting of Project Boreholes

Following the completion of the geophysics program, all the sounding data will be compiled into geoelectric sections which together with existing borehole information will provide a basis for the delineation of the vertical and areal extent of the Kalahari aquifer as well as for the identification of favourable sites in the Ntane sandstone formation.

The compilation of the data will avail the geometry of the perched aquifer and this will enable the positioning of boreholes optimally in relation to the geometry of the perched aquifer or aquifers for long term water supply as well as strategically in relation to the three villages.

The first few boreholes will be used to confirm the geometry and to continue investigating the potential of the Kalahari perched aquifer. Some of these boreholes may prove to be optimally positioned to exploit the perched aquifer. Otherwise optimal positioning with respect to yield, thickness,proximity to villages etc will be made for the production boreholes to supply the three villages. The supply points may eventually be in one area or distributed strategically to supply the respective villages from different points.

The most favourable sites in the Ntane sandstone formation will be drilled to test quantity, yield and sustainability of supply using long duration pumping tests.

3.3 Supervision of Drilling and Test Pumping Works

3.3.1 Background

The TOR stipulate that the client will enter a contract agreement with major registered CTB approved drilling and test pumping contractors. Geoflux will inform the client to appoint drilling and/or test pumping contractors at least two weeks prior to expected commencement of these activities according to the approved work schedule in the Inception Report or approved amended work plan in the monthly progress report. Geoflux will also inform the client on the technical requirements of the work to be carried out. This will help the client in the selection of the drilling and pump testing contractors. At the time of this notification Geoflux shall propose at least three (3) suitable contractors as well as provide drilling or test pumping requirements to the client.

The number of boreholes to be drilled and test pumped for the water supply of the three villages will be discussed between Geoflux and the client. Existing fresh water boreholes need to be properly pump tested before drilling of new boreholes.

3.3.2 Premobilisation Meeting

Geoflux will, after identification and appointment of a Contractor, arrange a Premobilisation meeting between themselves, the Client and the appointed Contractor to discuss the requirements of the planned operations. The meeting will discuss issues such as:

- borehole design and/or construction;
- grouting procedures;
- development techniques;
- depth and yield of pumping required;
- type and duration of test to be carried out;
- and any other matters related to the drilling and test pumping requirements or operations.

These meetings will be minuted by Geoflux and signed by representatives of both Geoflux and the contractor and submitted to the client for approval. The minutes thereafter will be read and construed as forming part of this contract document. The minutes will indicate clearly the dates on which the drilling and/or test pumping operations are to commence in the field.

3.3.3 Supervision of Drilling Works

Geoflux will ensure that all work is carried out according to good professional standards and in fulfilment of the agreed and Client's approved plan of operations and technical specifications. Daily drillers' work reports are to be collected, checked and certified by Geoflux on a daily basis and made available to the Client whenever required. Geoflux shall inspect the quality of material that will be installed on the boreholes, such as casing, screens and gravel and ensure that they conform to the specifications. Geoflux will produce a summary in the monthly progress report on the progress of works, the materials used and installed in boreholes. Geoflux will certify correct and satisfactory completion of works and correctness of contractors invoices.

3.3.4 Hydrogeological Monitoring of Drilling Works

The task shall include but not limited to the following:

- Recording of penetration rates using a stop watch for plotting graphic lithological logs.
- Estimation of airlift yields using a 90° V-notch weir and a container of known volume.

- Logging of lithological drill samples.
- Recording of all hydrogeologically relevant observations and sorting borehole construction details for archive purposes.
- Conductivity monitoring at different water strikes to determine freshness or salinity of the water.
- Monitor changes in drilling techniques i.e change of tools, diameter of drill bit before and after insertion and the use of water or foam.

Geoflux proposes the drilling of monitoring or exploration boreholes near production (exploitation) boreholes as observation wells in order to facilitate calculation of storage coefficient and quantification of the groundwater resource in the area.

> **GEOFLUX SOFTWARE**
>
> ACTIF: Collection, storage, printing and graphical presentation of all parameters collected during drilling.

3.3.5 Organisation and Execution of Pumping Tests

The pumping tests will consist of calibration test, step drawdown, constant yield and recovery. Interference testing will be carried out at selected sites where observation boreholes exist.

Technical specifications will be given to the Contractor by the Consultant (Geoflux) at the Premobilisation Meeting in accordance with the contract document for drilling and test pumping works. The Consultant will propose at least two suitable test pumping contractors one of which will be appointed by the Client. The Consultant will notify the Client to appoint a test pumping Contractor at least two weeks prior to the expected date of commencement of the test pumping operations according to the agreed or approved work schedule. The Consultant will ensure that the pumping tests are carried out professionally according to standards set out in the Geological Survey form GS 183 part A and B and that the data collected are of reliable quality. The tests shall be carried out with the objective to determine aquifer parameters and borehole performance (production boreholes). The Consultant will propose the boreholes to be tested and the tests will be carried out only in boreholes approved by the client and whenever possible using old and/or new boreholes nearby as observation boreholes. Data collection and interpretation will be done by the Consultant and all preliminary data plotting and interpretation will be carried out on site so to adjust the test to best suit local conditions. A copy of the test pumping data for the project shall be handed over to the

Client on 3 1/2 inch disk on submission of the draft final report.

Water levels in monitoring or exploration boreholes drilled near production boreholes will be monitored continuously during pumping tests.

Geoflux proposes the test pumping of some existing boreholes with relatively high yields and monitoring of water levels in nearby boreholes and/or hand dug wells. In order to evaluate the hydraulic parameters of the perched aquifer it will be necessary to test pump some existing and equipped boreholes. Step drawdown tests will be necessary to assess the aquifer and well performances at variable pumping rates.

All four equipped boreholes in Tshane should be step tested in order to evaluate well efficiencies. The step tests must be followed by proper long duration pumping tests (48 hours). Existing pumping test data for boreholes 6482 and 6484 is of doubtful quality.

All five equipped boreholes in Hukuntsi should be step tested followed by 48 hours constant rate tests. These boreholes were either never pump tested after they were drilled or existing test pumping data is of poor quality.

The three equipped boreholes in Lehututu require to be step tested followed by long duration (48 hours) constant rate tests. Borehole 6088 must be test pumped (step test and constant rate test) in order for it to be equipped to augment the village water supply.

GEOFLUX SOFTWARE	
ACTIF:	Collection, storage, printing and graphical presentation of every parameter collected during drilling, including interpretation of step drawdown tests ($s/Q = f(Q)$ and headlosses)
ISAPE:	Semi-automatic interpretation of pumping test data and simulated behaviour of waterwells for various hydrogeological contexts.

3.4 Groundwater Sampling, Analyses and Quality Assessment

Water samples will be collected for analysis from existing boreholes and selected hand dug wells during the field inventory and during pump testing of the project boreholes. Water samples from water strike horizons, pumping tests and samples from existing boreholes are to be submitted to DWA water analysis laboratory for standard major ion analyses.

The analysis will be interpreted to determine their relationship to lithology, groundwater flow, hydrochemical evolution trends, recharge and potability. Microbiological analysis may be required at specific boreholes where pollution is suspected.

3.5 Position and Levelling

3.5.1 Positioning and Levelling of Boreholes

To overcome problems of poor accuracy of positioning through airphotographs in areas where it is aggravated by featureless terrain (such as shrub-dominated Kalahari cover areas) and by poorly produced airphotographs, the Consultant will augment the use of airphotographs, satellite imagery with the use of a GPS Receiver.

Geoflux will to position and level selected inventory boreholes with useful information and project boreholes using a Trimble 4000 ST Field Surveyor GPS Receiver. Other boreholes will be positioned in X,Y to an accuracy of ± 30m.

Levelling of boreholes is optional to the Client and is recommended by the Consultant for assisting in the establishment of a piezometric map through levelling of productive boreholes and selected hand dug wells. The levelling of boreholes will also assist in accurately defining the aquifer geometry at known points, correlation of lithological units and determination of any relative vertical displacements, and indications of local topographic variations.

3.5.1.1 Principal Approach

Surveying of boreholes in different mode will be done using 2 Trimble 4000ST Field Surveyor GPS receivers in differential mode.

In this approach two GPS receivers are set up at two stations simultaneously tracking the same satellites. One receiver is set up at a station with known coordinates e.g a bench mark or trigonometric beacon whilst the other is at an unknown point whose coordinates are to be established. With simultaneous tracking of the same satellites, the latitude/longitude difference as well as the height difference between the two points is established. In this manner it is then possible to determine the coordinates X, Y, Z of the unknown point. With the present constellation of 18 operational satellites and available planning, prediction and post processing software, it is possible to predict the daily satellite visibility in Botswana for any given month in order to plan and execute the survey during the times when the required minimum number of satellites (4) are available for high accuracy positioning.

The complexity of the survey in planning, execution, and processing requires the expert services of a qualified surveyor.

3.5.1.2 Field Approach

i) Establishment of a Control Point Nearer the Boreholes/Village

A control point coordinated in X, Y, Z will be established at a position proximal to or within the project area. This position will not be more than 10km from the furthest borehole to be surveyed in order to achieve the required accuracy for elevation determination.

The standard procedure of levelling of existing bench marks or trig beacons near the project area will be done to the bench mark(s) to be used. This is done as a check to make sure that the bench marks have not been disturbed since they were built. After the bench marks have been levelled the height differences obtained among them will be compared to the ones supplied by the Department of Surveys and Lands. Once satisfactory results are obtained then the bench marks can be used to establish the control points elevation. Occupying existing bench marks and trig beacons will enable a transformation of GPS horizontal coordinates to the national trig system and GPS heights to heights above mean sea level.

ii) Surveying of Boreholes

Two GPS operational modes will be used. Where boreholes are close to each other and there are no obstacles (mostly trees), the kinematic mode will be used. In this mode one GPS receiver is left as a base station and the other will be moving from borehole to borehole. Where dense vegetation occurs, the static mode will be used.

All boreholes levelled will be fixed to an accuracy of 0.1m in height and less than 1.0m in horizontal position. Where possible the GPS receiver will be set up over the borehole casing or cement slab and the height/length of the casing or slab measured. Experience in the country in these type of surveys shows that some boreholes are sheltered or obstructed by trees. In such a situation a GPS station will be established near the borehole and a total station will be used to fix the actual borehole from the GPS station. To obtain a correctly oriented direction from the GPS station to the borehole involves establishing an additional GPS station some few hundred metres away. This is an exercise which takes some satellite availability time without significantly improving the accuracy. It is proposed that the total station be used for borehole elevation determination and measurement of distance from the GPS station to the borehole. The direction from the GPS station to the borehole can be obtained much quicker with a magnetic compass. No great loss of accuracy is expected from using a compass at this stage because the GPS station will normally be <u>within 20m</u> from the borehole and is well within the X - Y specifications for this project.

3.5.1.3 Equipment Specifications

a) GPS

2 x Trimble 4000ST Land Surveyor GPS Receivers and data logger.

Static Survey

Horizontal: 1cm + 2ppm times baseline length
Vertical : 2cm + 2ppm times baseline length

Kinematic Survey

Horizontal and Vertical: 2cm + 2ppm times baseline length

b) Total Station

A Wild TC 1600 total station is a combined theodolite and distance measuring instrument which determines height differences using the method of trigonometric heighting.

Accuracy:

Slope distance: 3mm + 2ppm
Angular : 1.5 seconds

3.5.1.4 Data Processing

Data processing and analyses will be done using Trimvec-Plus GPS post-processing software on a 386 laptop computer. The software enables processing of GPS survey data for both kinematic and static modes and will produce coordinates in lat/long height as well as UTM. In addition to post processing, the software also provides a planning facility with satellite availability times and their PDOP (position dilution of precision). The PDOP is a measure of the quality of data to be expected after tracking satellites at any given time. With the facility it is possible before going to the field to determine the best time to undertake a survey. The Trimvec Plus software also provides a facility for Traverse closure analysis. This facility will be used for determining misclosures for observations made on a closed loop as in conventional surveying. In addition there is a provision for error ellipses which graphically show the potential accuracy of each point coordinated.

On completion of the survey a coordinate list of the boreholes will be produced. This will be accompanied by a plot of the borehole positions to be drafted at a scale 1:50000.

3.6 Estimation of Recharge - Renewable Resources

In the project area, a recharge assessment will be carried out:

- to identify potential recharge areas;
- to quantify recharge.

As far as groundwater is concerned, recharge will be appreciated on a long term basis by using climatology and chloride content data.

3.6.1 Identification of Potential Recharge Areas

Global estimate of recharge obtained from the long term data (evaporation/rainfall, chloride mass balance) will be weighted and discretized after identification of potential recharge areas.

Potential recharge areas will be delineated based on:

- existing geomorphological and soil distribution mapping, air-photo interpretation and ground-checks;
- combined interpretation of data sets such as:
    * low chloride values/piezometric highs;
    * coincidence of extensive areas of thin or non existent cover/low chloride values;
    * significant thickness of alluvial deposits in river courses/extensive areas with calcrete;
    * fossil drainage lines, pans.

3.6.2 Recharge Quantification

a) Climatology

The project area has a semi-arid, sub-tropical climate. Frequent droughts occur. Most rainfall is poorly distributed in terms of both time and space. Monthly and annual rainfall never exceeds potential evapotranspiration, but recharge may occur at shorter intervals.

Knowledge of the amount and distribution of short rainfall events is desirable for anlysing possible recharge events. Therefore daily rainfall and other meteorological data will be collected from the Department of Meteorological Services. Data stations with long period of observations will be preferably selected.

Average monthly climatic parameters entering in the calculation of the open water evaporation (OWE) and potential evapotranspiration (PET) with the Penman formula have been sourced from the Department of Meteorological Services for Tshane village and these include:

- rainfall;
- evaporation;
- sunshine duration;
- average wind speed.
- minimum temperature

The reliability of data will be assessed and whenever possible missing data will be infilled by correlation with nearby reliable stations.

The interpretation of potential evaporation and evapotranspiration will consist of:

- computerised data collection and storage;
- assessment and appreciation of the reliability of data, whenever possible missing data will be infilled by correlation with nearby reliable stations;
- analysis of rainfall data and statistical processing of such data highlighting interannual and seasonal rainfall variation and its spatial distribution;
- calculation of evaporation and evapotranspiration with the modified Penman Formula;
- synthesis of data.

b) <u>Chloride Contents in Groundwater</u>

Samples of groundwater will be collected by the Consultant for chloride concentration analysis by the DWA at their chemical laboratory. The sampling will be carried out during the fieldwork phases of the project.

Groundwater sampling will be carried out simultaneously as part of the overall chemical monitoring programme.

The method of interpretation involves comparison of the concentration of chloride in rainwater, with that of groundwater to deduce the dilution by rain and thus the average infiltration rate, according to the following formula:

$$R = \frac{Pc_p + D}{C_{gw}}$$

Where R = rate of recharge
P = precipitation
D = dry chloride deposition
C_p = chloride concentration in precipitation
C_{gw} = chloride concentration in groundwater

3.7 Resources Evaluation

The groundwater resources of the project area will be assessed both qualitatively and quantitatively at the end of the project. The following aspects will be achieved.

- aquifers and aquicludes will be identified and delineated;
- aquifers will be characterised in terms of their hydrodynamic properties (K, T and S);
- the geometry of the aquifers and aquicludes will be established;
- regional picture of groundwater head and flow directions will be established;
- aquifer conditions (confined and unconfined) and the degree of confinement, where applicable, will be established;
- the regional picture of salinity distribution of the groundwater will be established through electrical conductivity and total dissolved solids (TDS);
- the lithostratigraphical unit(s) in which saline water is first struck and confined to will be identified;
- recharge areas and rates of recharge to the aquifers will be established.

3.8 Exploitable Resources

Analytical solutions will be used to achieve the following:

- quantifying groundwater resources which can be economically developed and to recommend rates of abstraction and pump settings;
- delineation of areas suitable for the installation of future wellfields;
- calculation of the aquifer lifetime under various assumed abstraction scenarios.

Aquifer modelling may be attempted, using the commercially available package "MODFLOW", if sufficient and appropriate data becomes available.

3.9 Environmental Impact Assessment

Commentary will be made on possible environmental impacts and adverse effects on existing users that may be caused by the proposed utilisation of the identified groundwater resources. This will be achieved by a study of the physical and socio-economic activities in the area that are likely to be affected by the development and utilisation of the groundwater resources.

The present environmental impact in the area is due to the socio-economic activity related to farming (arable and pastoral) and attendant activities.

3.10 Reporting

Reports will be prepared by Geoflux in accordance with the conditions of engagement and submitted to DWA.

a) Inception Report

Four copies of the Inception Report (this stage) will be submitted at the end of the first month (4 weeks). This report:

- presents a review of all existing information and data;
- presents results of airphoto interpretation;
- defines the selected target areas for ground geophysical investigations. Such target area selection have been justified according to structural and/or other geological or hydrogeological criteria used;
- identifies the most appropriate techniques for investigating the selected target areas;
- outlines the detailed plan for the work to be carried out.

b) Telefax Reports

Weekly progress reports will be sent to DWA by telefax as required in the Terms of Reference. In addition, if major problems requiring urgent decisions arise, Geoflux will contact DWA by telephone immediately. Any such communication will be followed up by a telefax summarising the telephone discussion. A weekly report will still be sent for that week at the appropriate time.

c) Monthly Progress Report

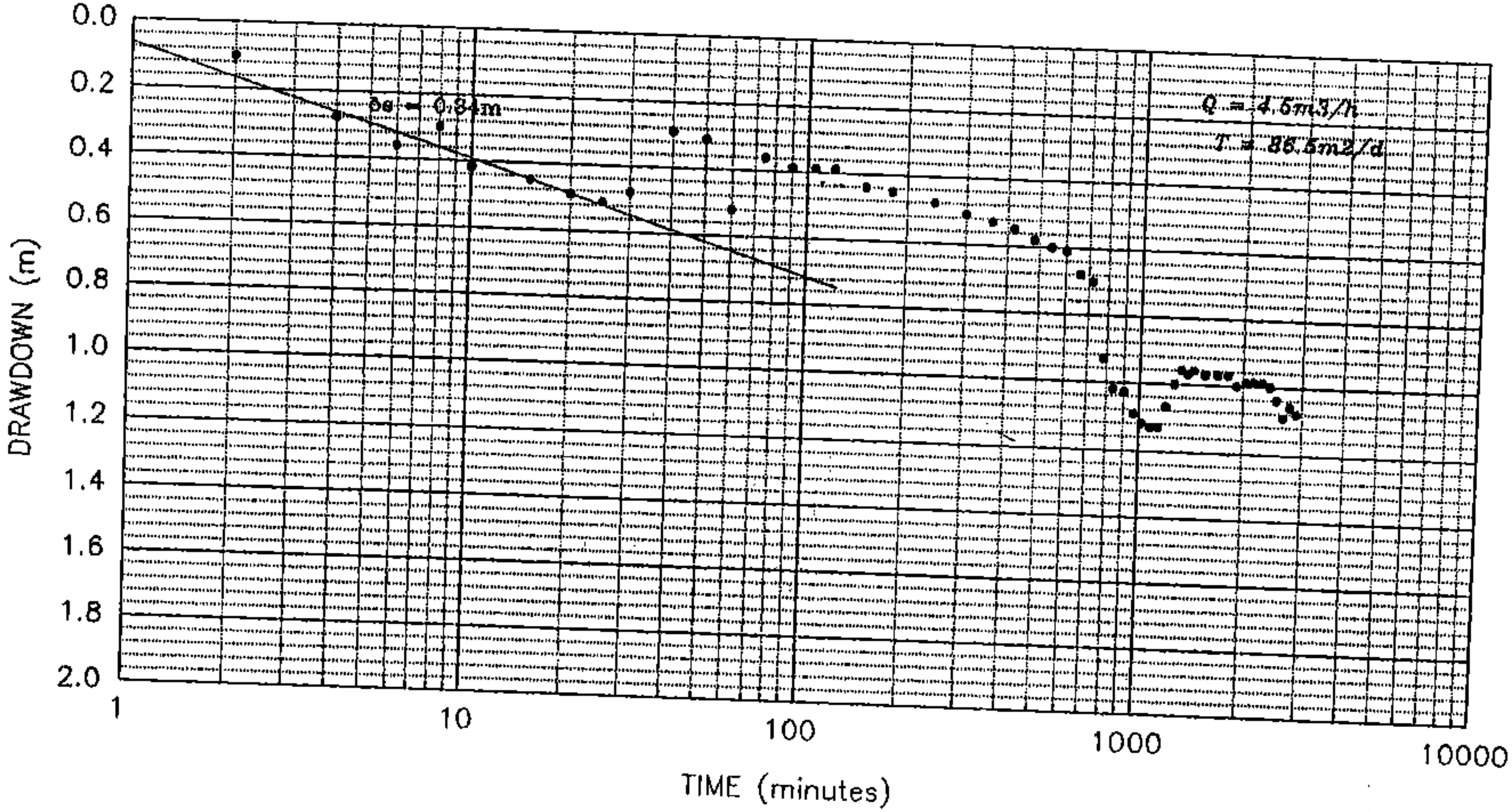
Monthly Progress reports (4 copies) will be prepared by Geoflux and presented to DWA as required. In addition to the work status and plans for future work, the report will present up to date

APPENDIX 1.5.1

PUMPING TEST GRAPHICAL PLOTS OF EXISTING BOREHOLES

LEHUTUTU – CONSTANT DISCHARGE RATE TEST BH 5947

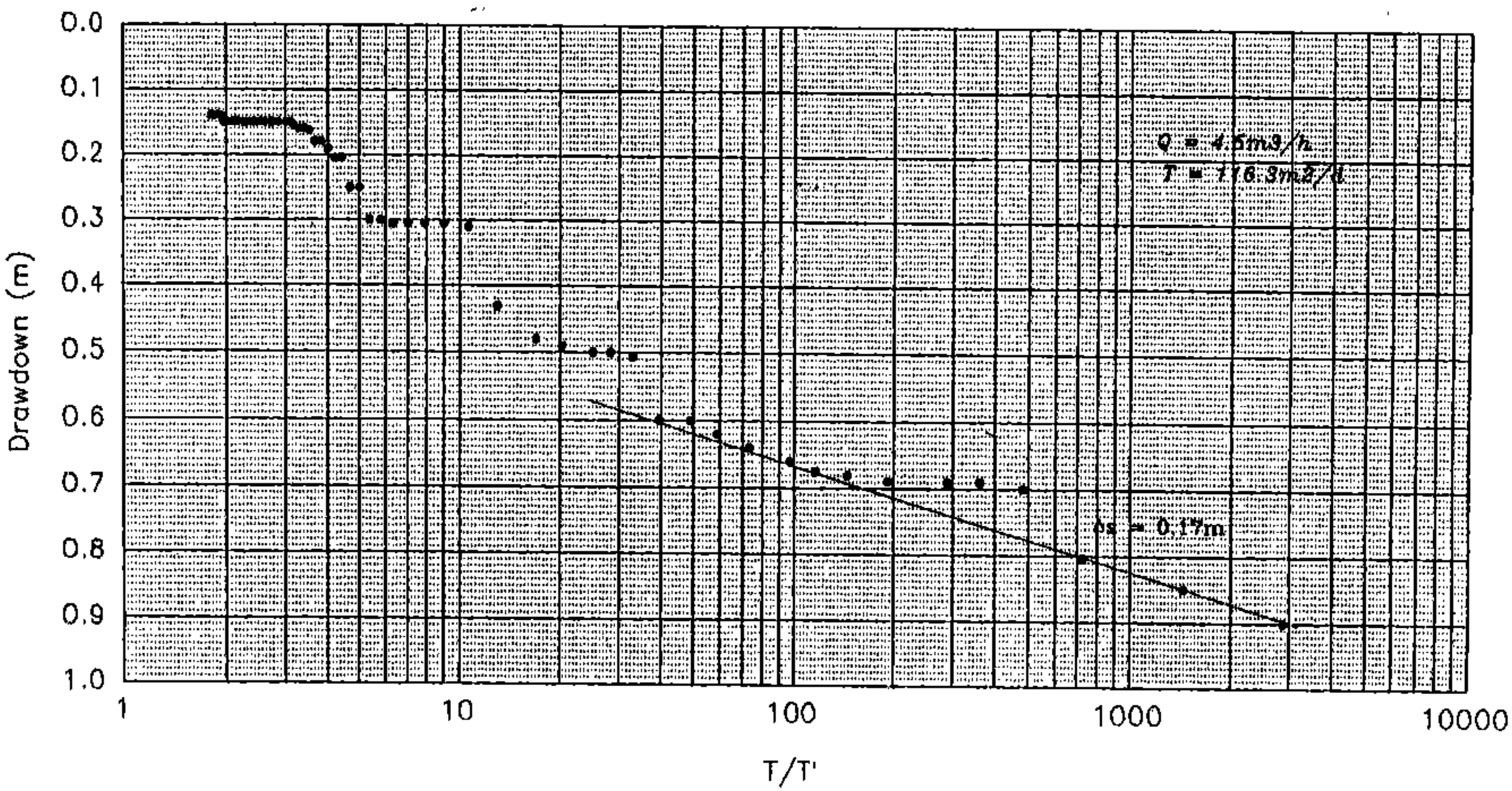
SWL 12.60 m



GEOFLUX (PTY) LTD

RESDIDUAL DRAWDOWN ANALYSIS BH 5947

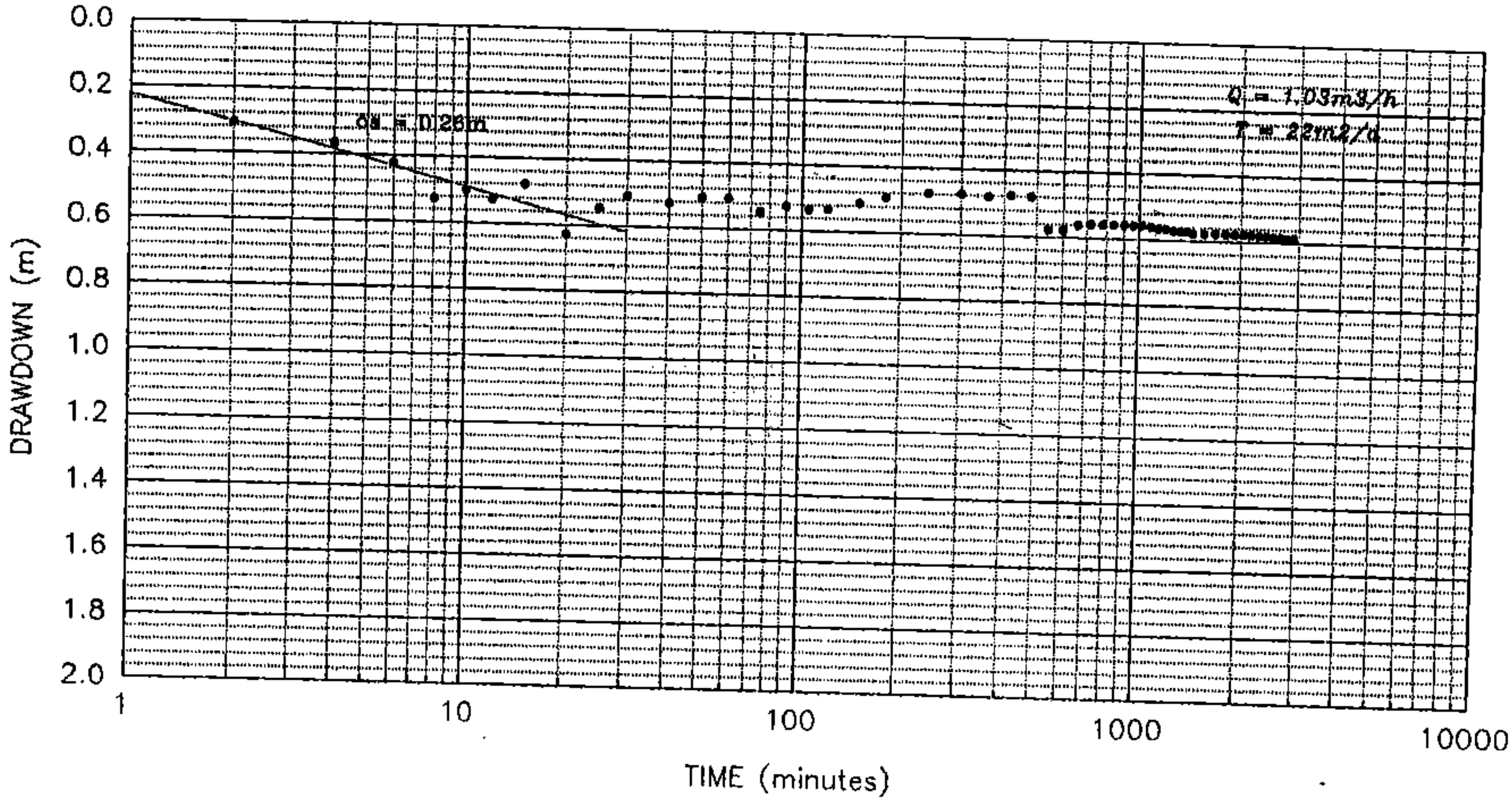
swl = 12.60 m



GEOFLUX (PTY) LTD

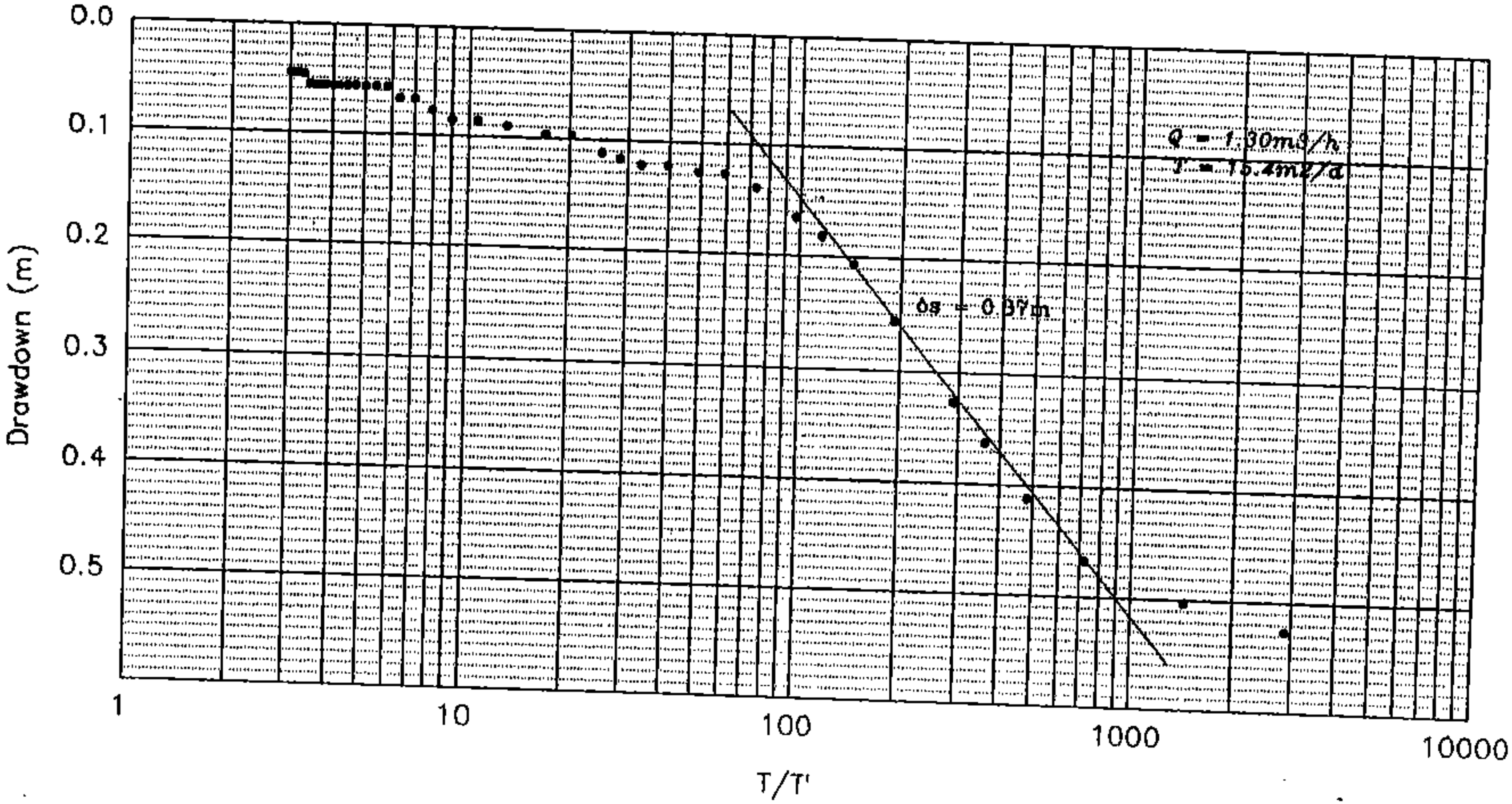
LEHUTUTU – CONSTANT DISCHARGE RATE TEST BH 5948

SWL 12.143m



RESDIDUAL DRAWDOWN ANALYSIS BH 5948

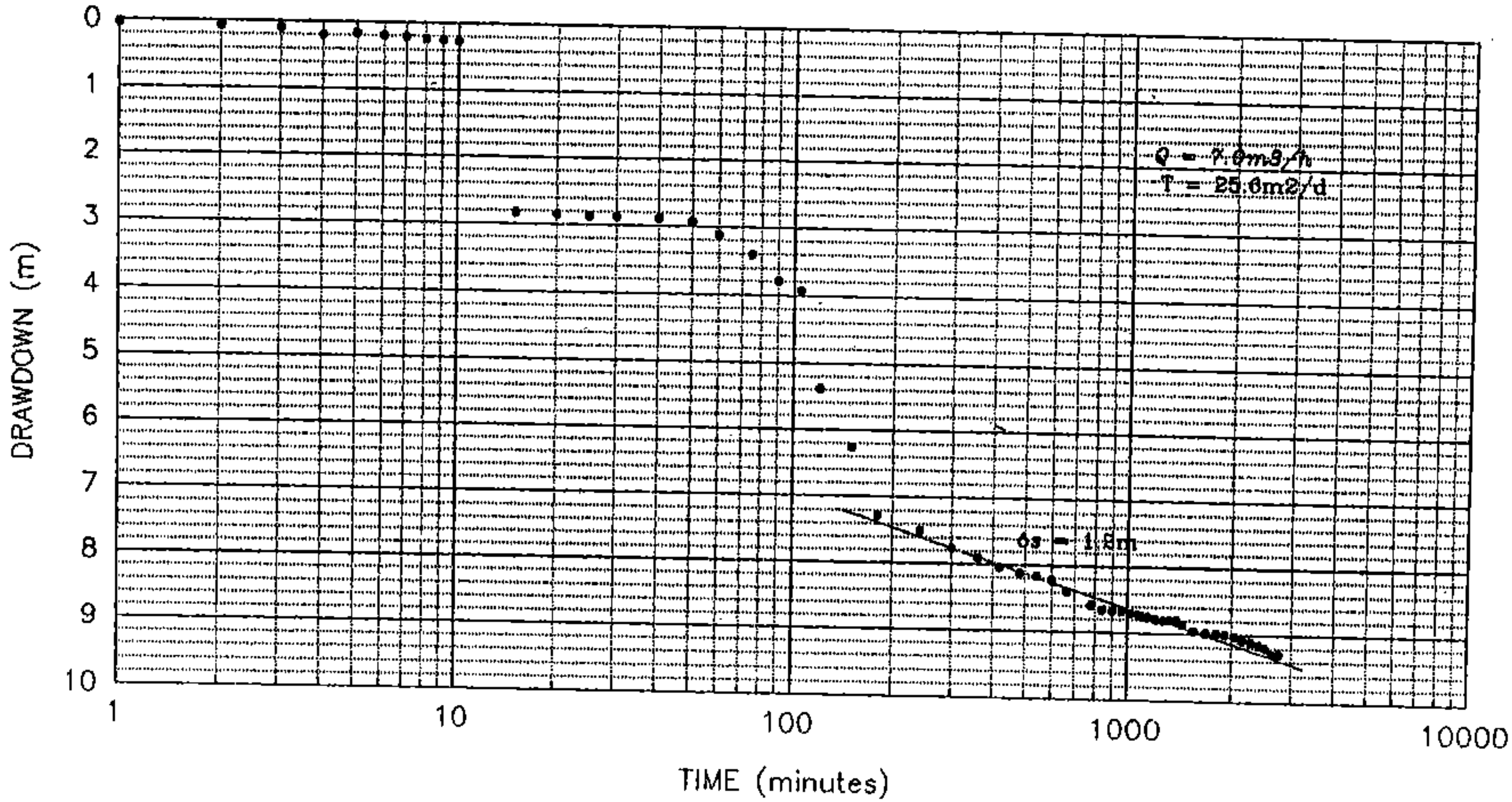
swl = 12.413 m



GEOFLUX (PTY) LTD

LEHUTUTU – CONSTANT DISCHARGE RATE TEST BH 5968

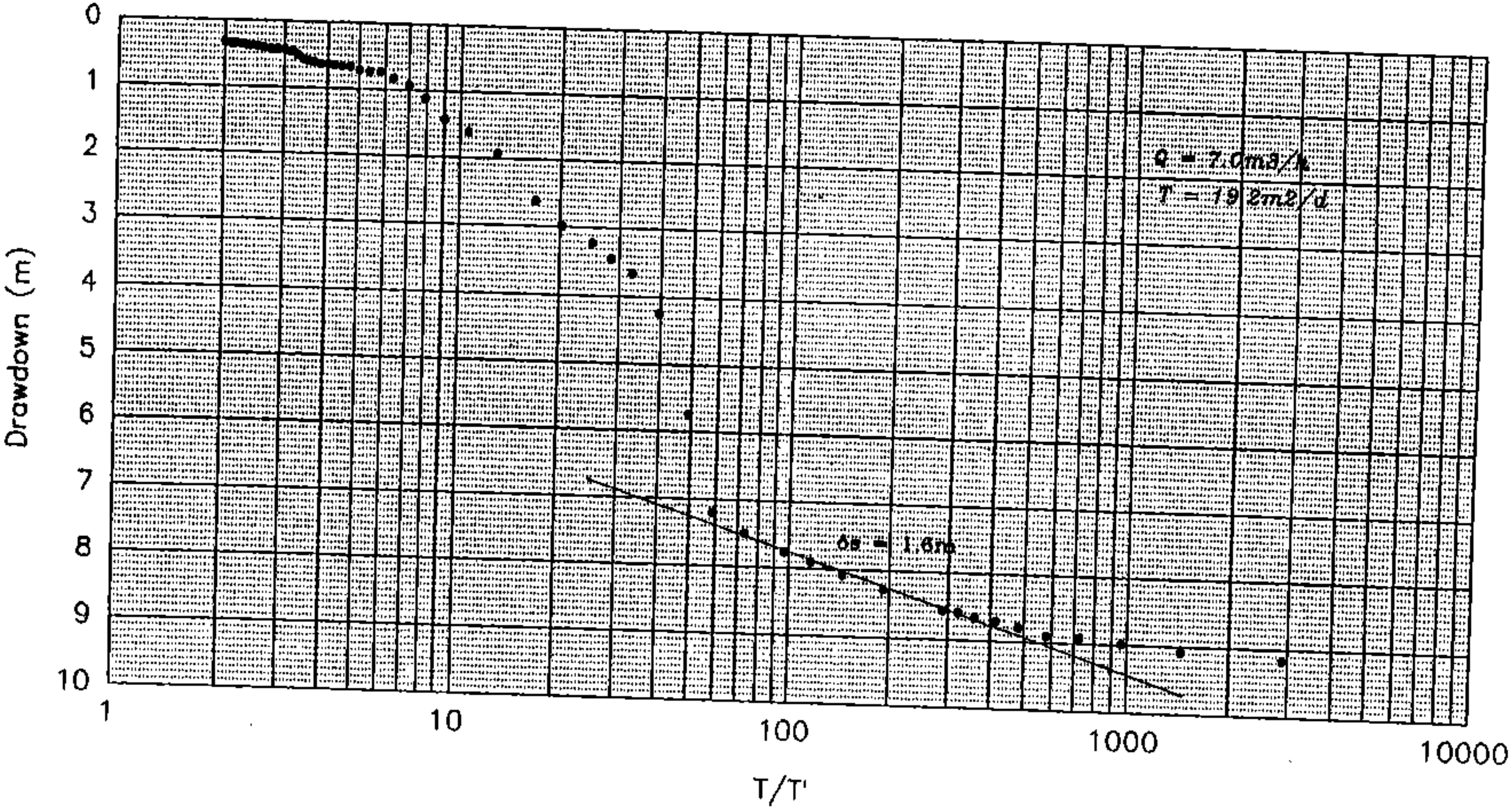
SWL 17.67 m



GEOFLUX (PTY) LTD

RESDIDUAL DRAWDOWN ANALYSIS *BH 5968*

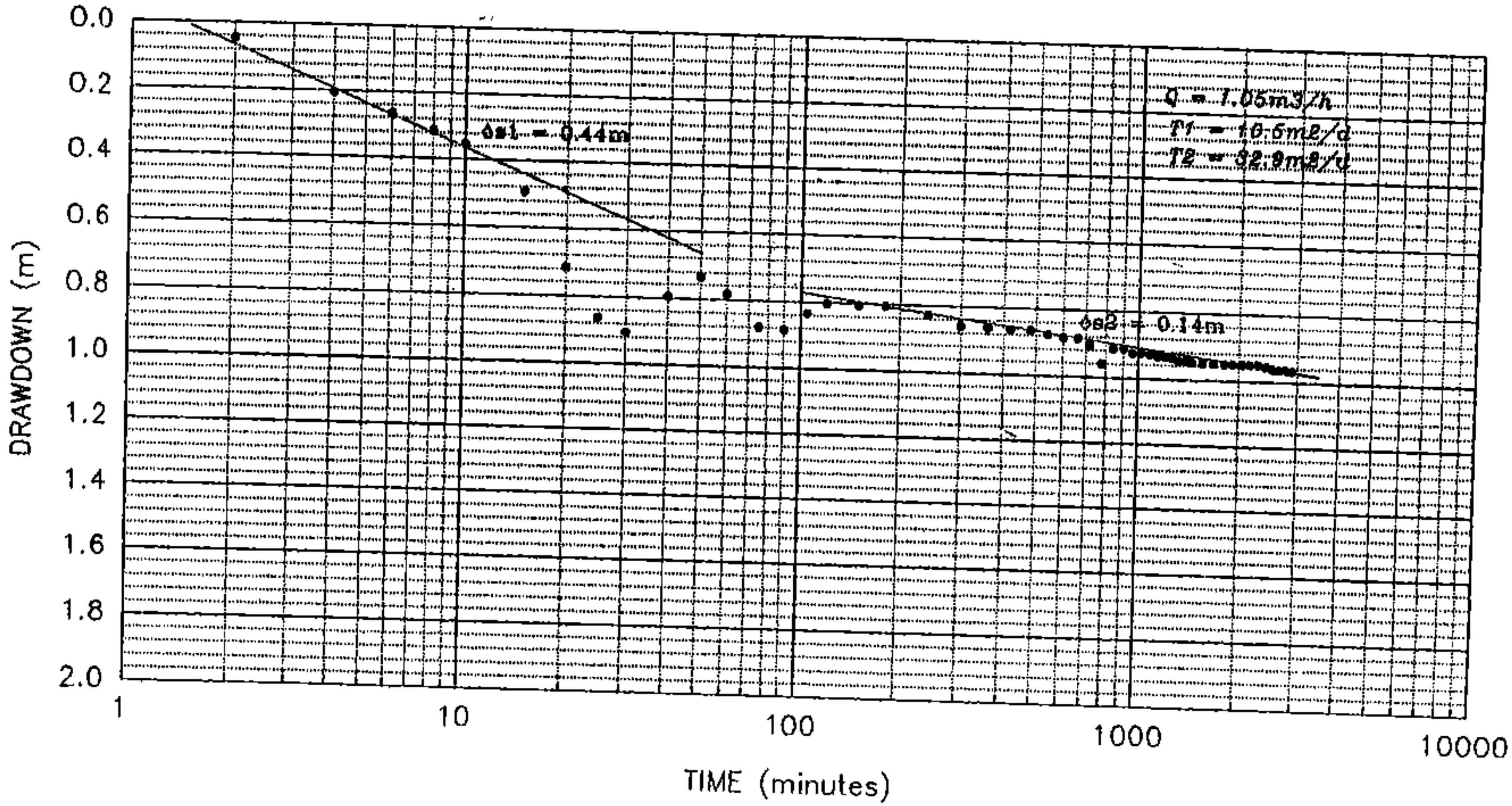
swl = 17.67 m



GEOFLUX (PTY) LTD

LEHUTUTU – CONSTANT DISCHARGE RATE TEST BH 6046

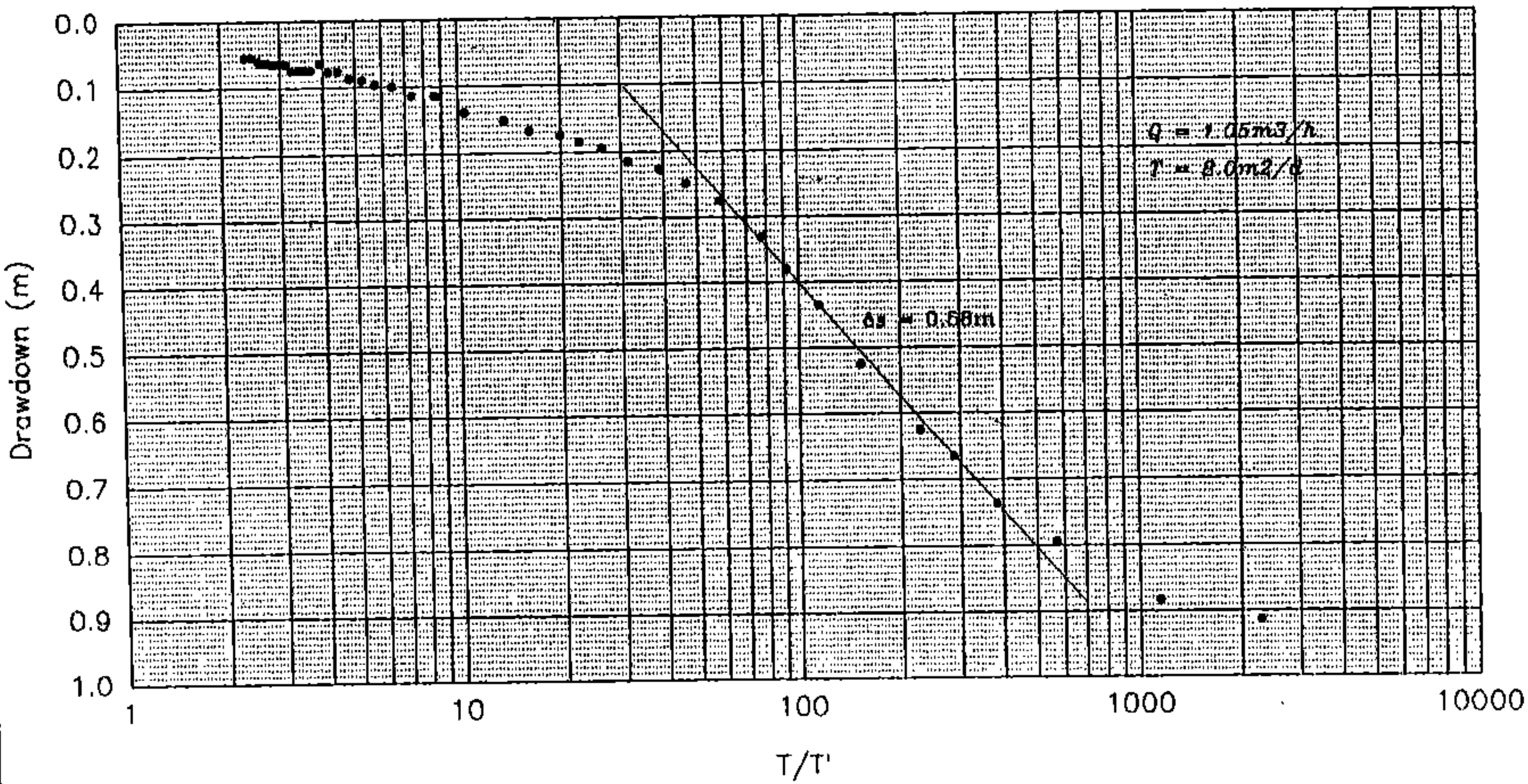
SWL 13.335 m



GEOFLUX (PTY) LTD

RESDIDUAL DRAWDOWN ANALYSIS BH 6046

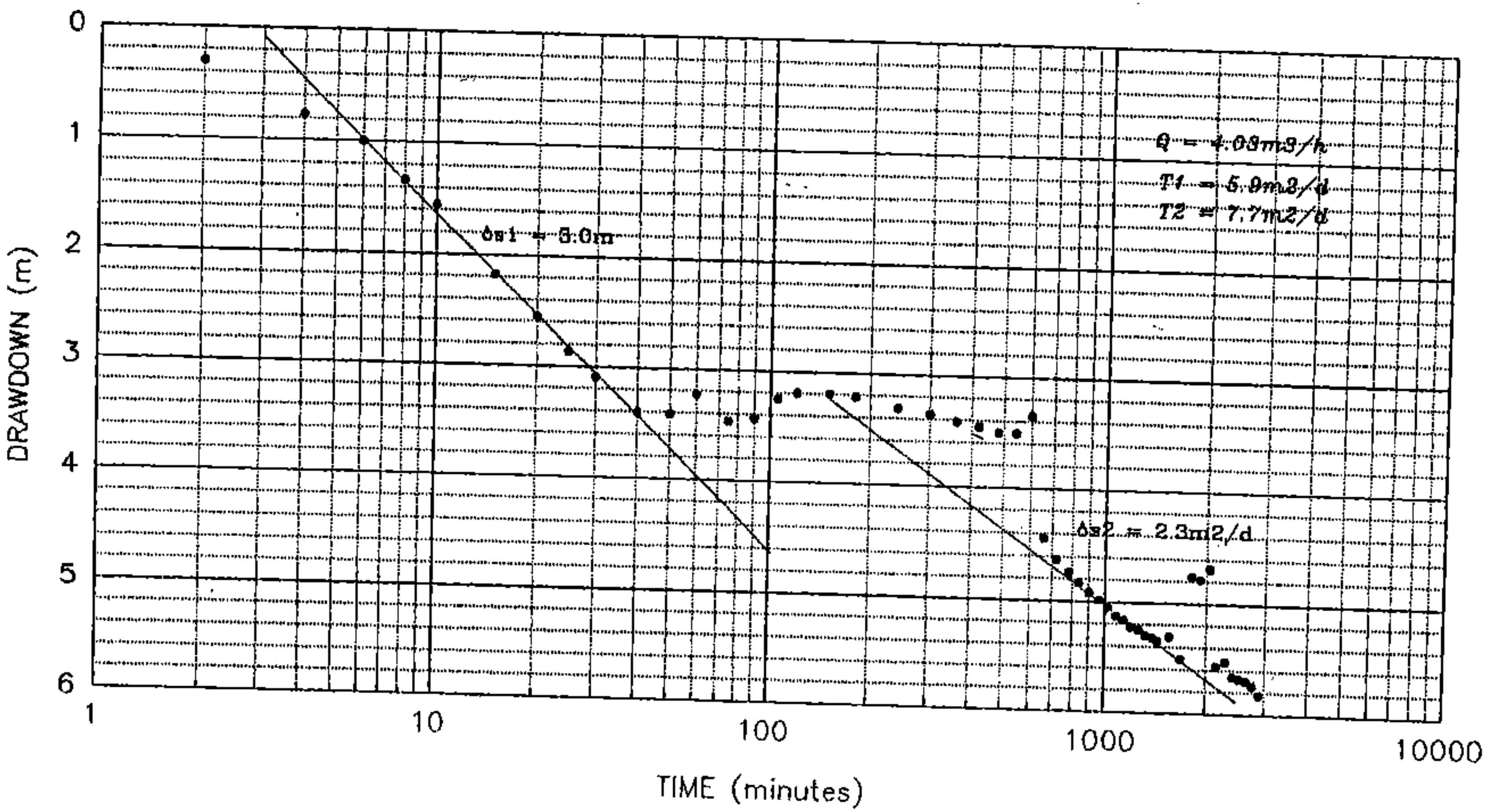
$wl = 13.335m$



GEOFLUX (PTY) LTD

LEHUTUTU -- CONSTANT DISCHARGE RATE TEST BH 6088

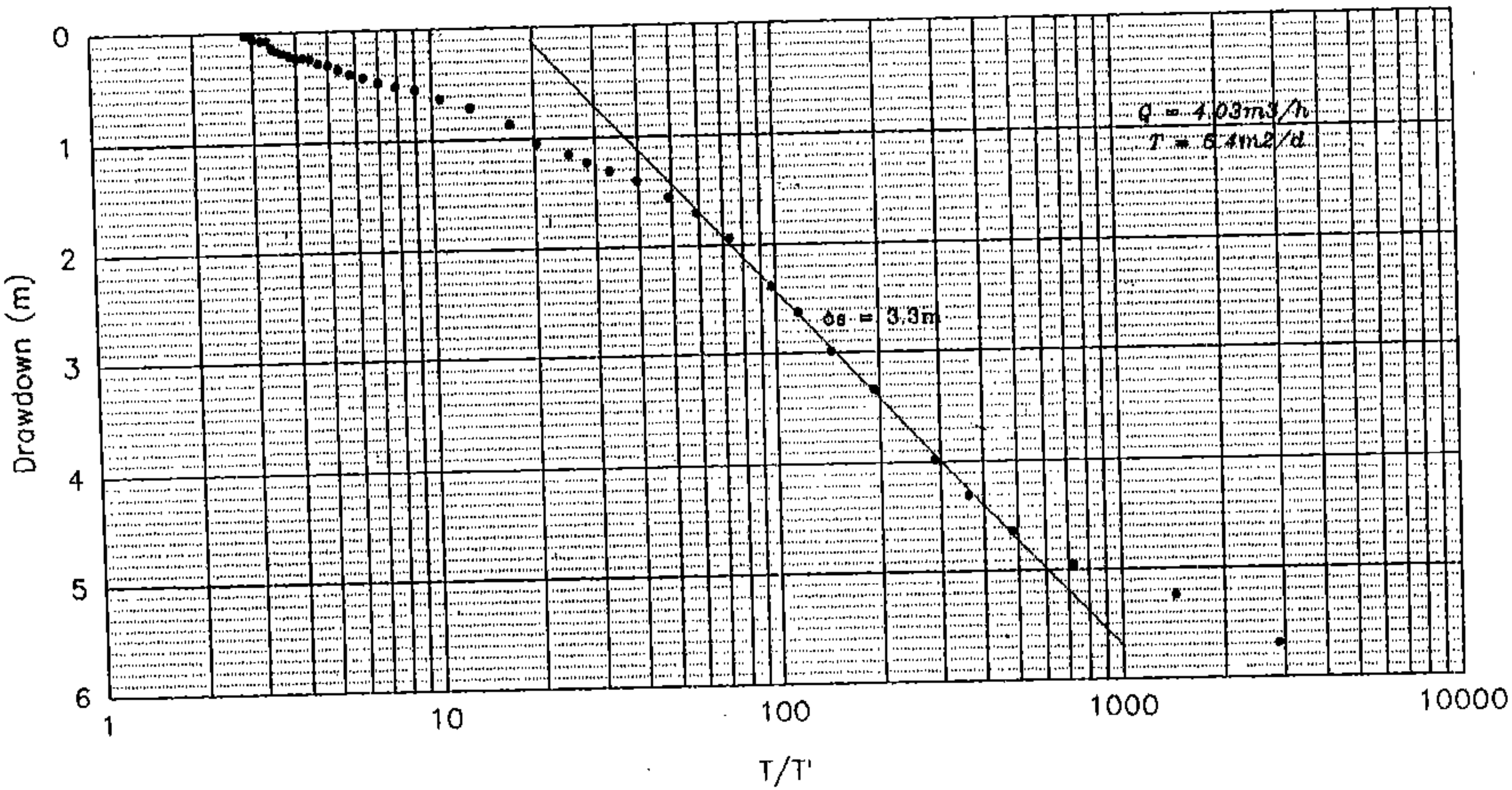
SWL 13.401 m



GEOFLUX (PTY) LTD

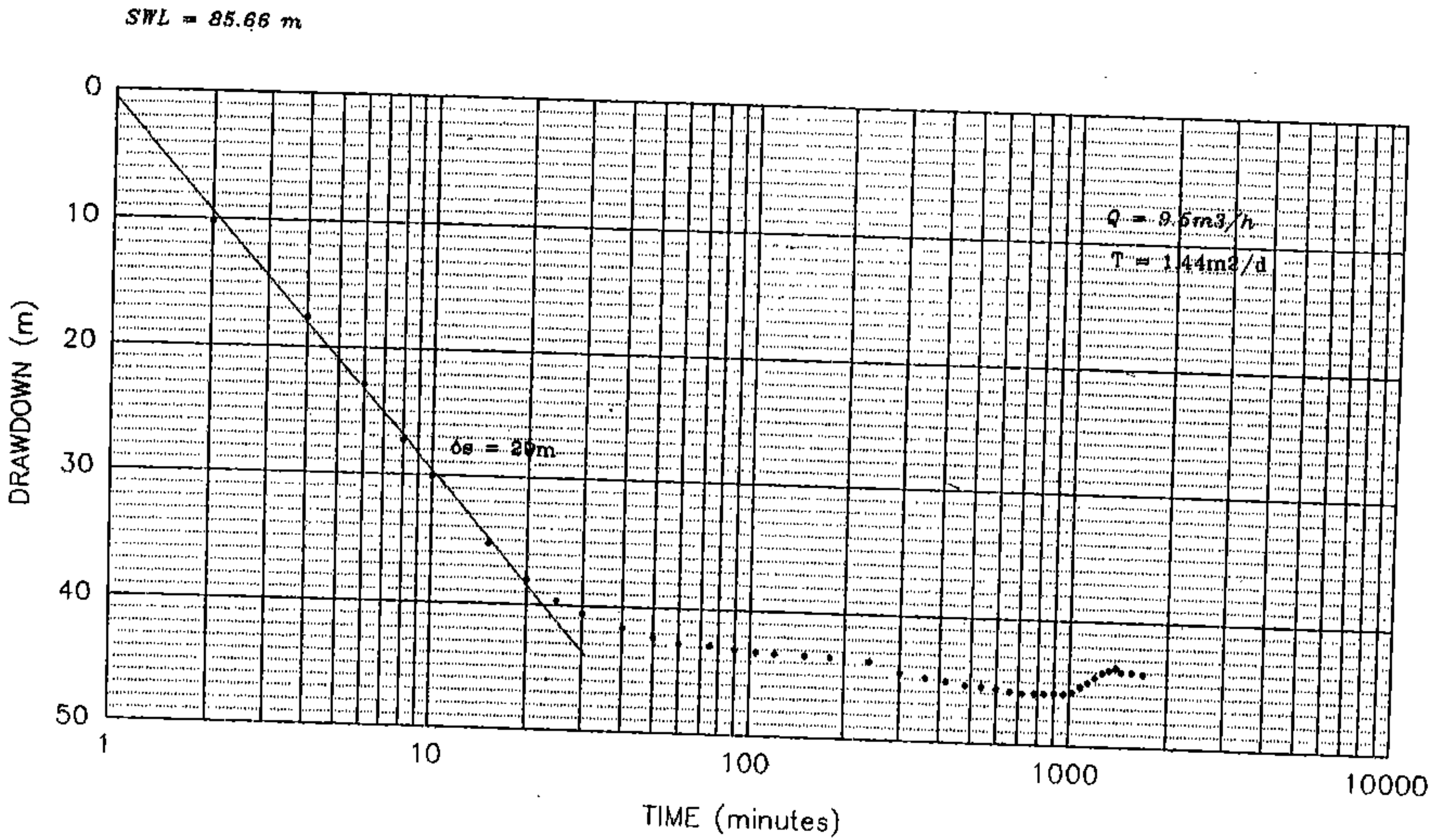
RESDIDUAL DRAWDOWN ANALYSIS   BH 6088

swl = 13.401m



GEOFLUX (PTY) LTD

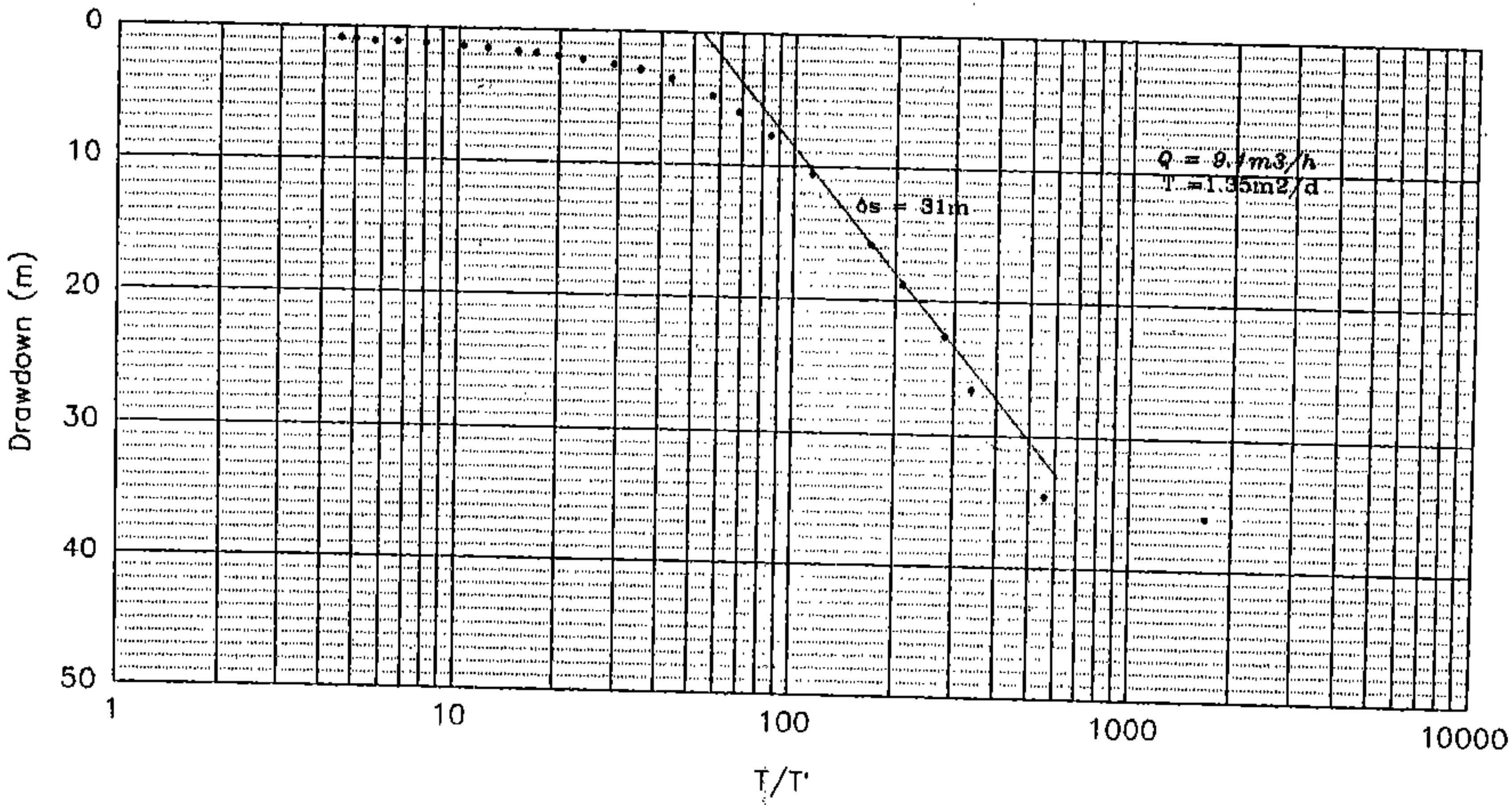
TSHANE CONSTANT DISCHARGE RATE TEST BH 6481



GEOFLUX (PTY) LTD

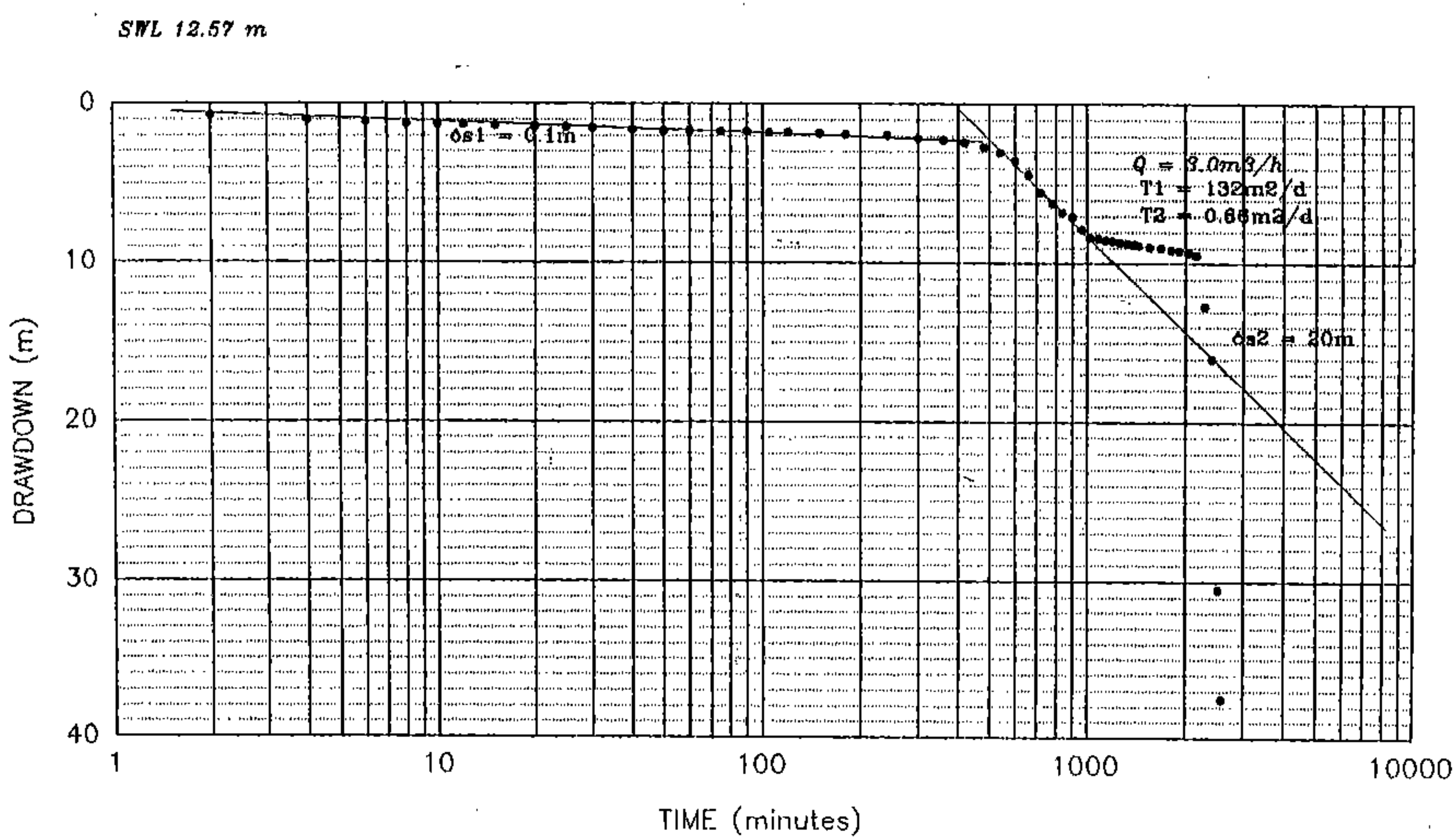
RESDIDUAL DRAWDOWN ANALYSIS BH 6481

swl = 85.66m



GEOFLUX (PTY) LTD

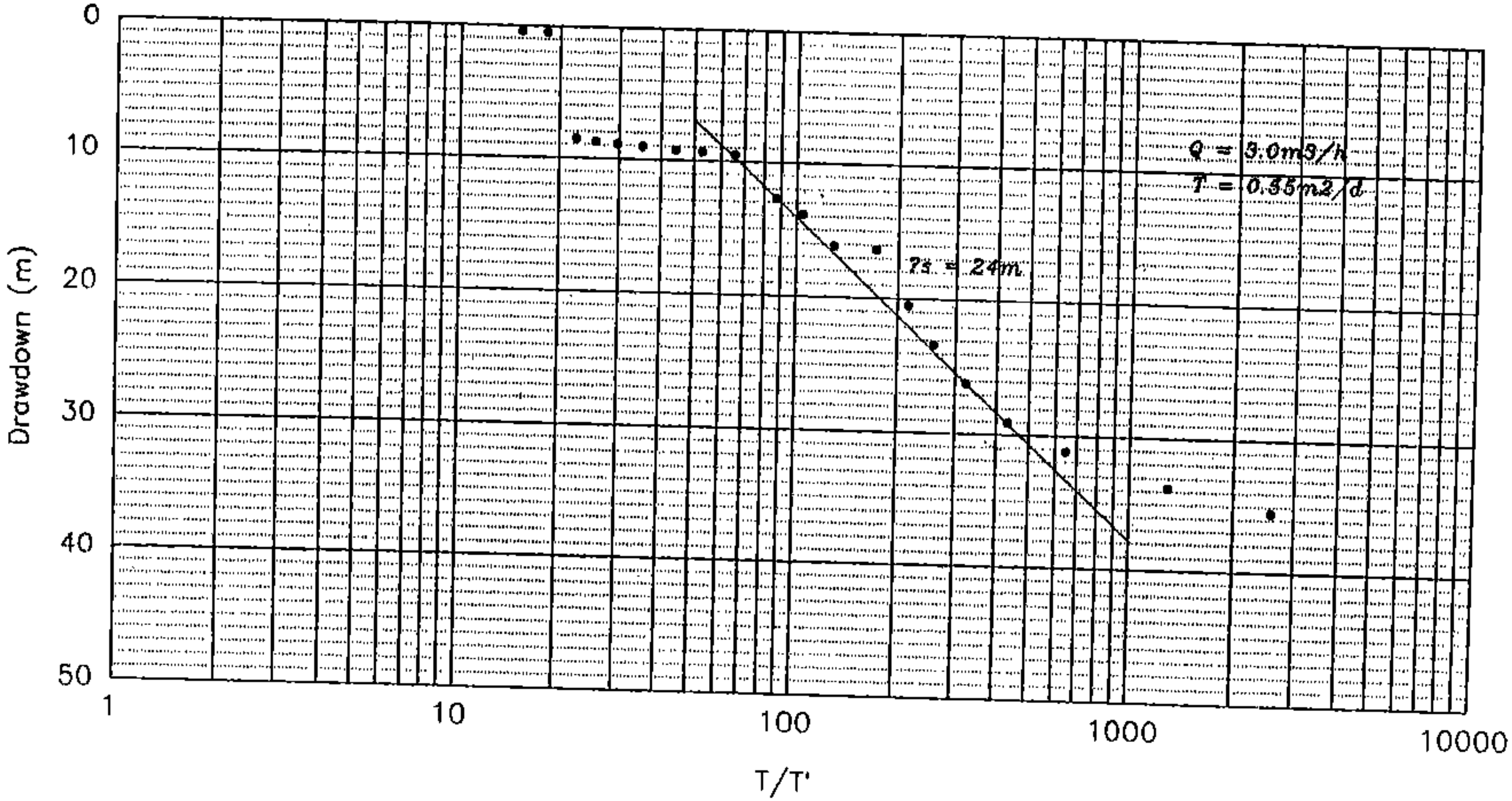
TSHANE CONSTANT DISCHARGE RATE TEST BH 6482



GEOFLUX (PTY) LTD

RESDIDUAL DRAWDOWN ANALYSIS   BH 6482

swl = 12.57m



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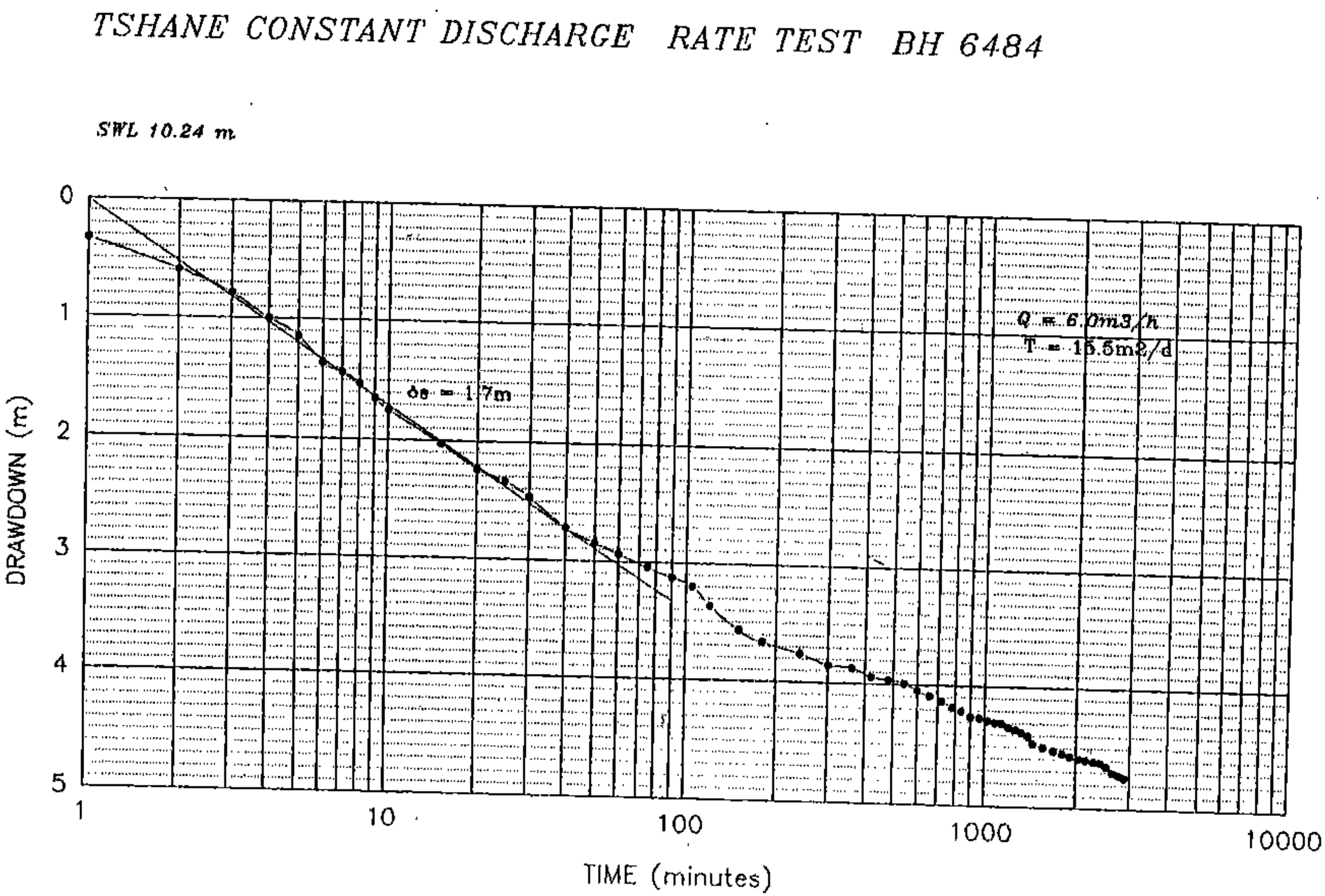
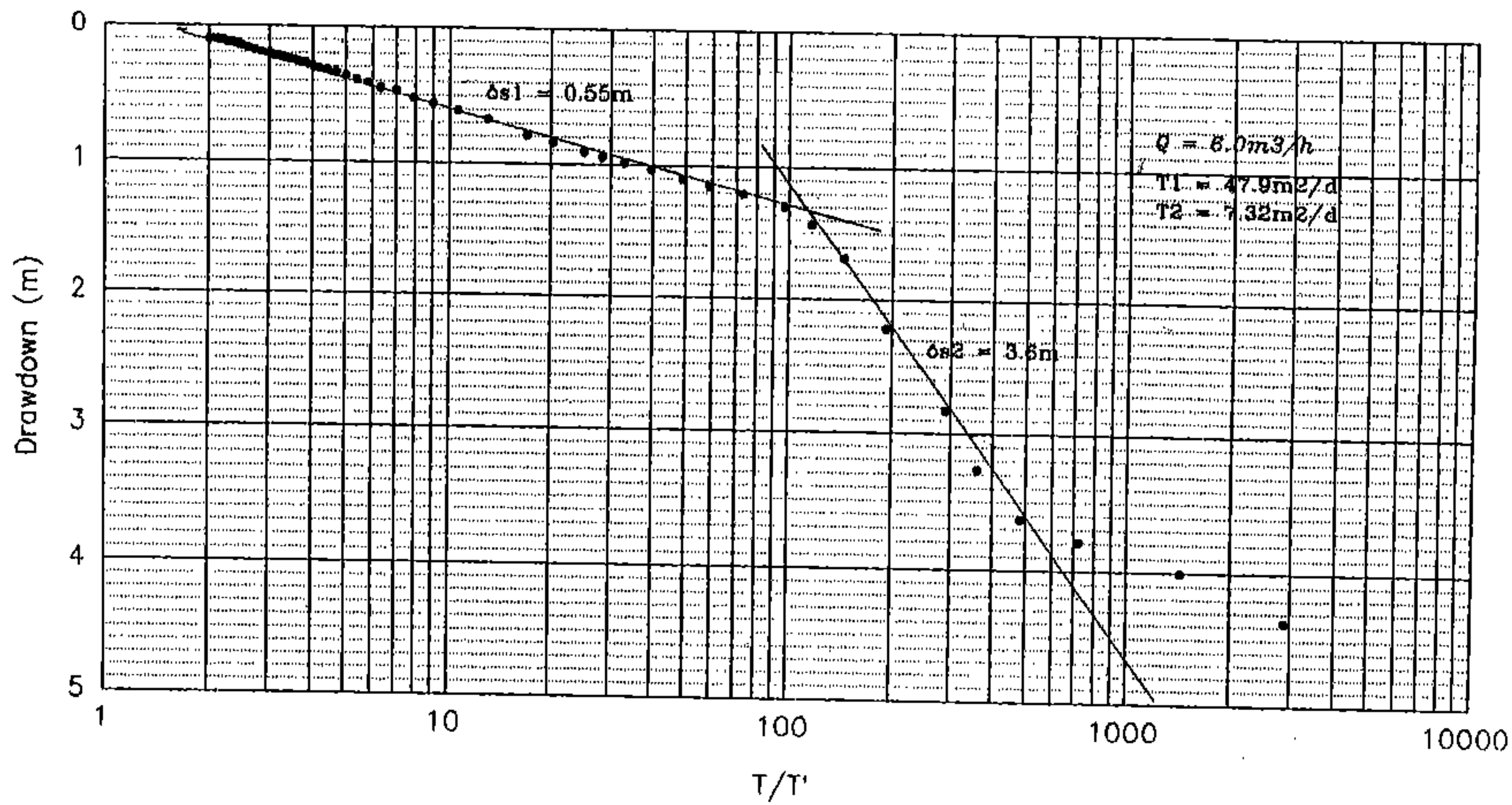


GEOFLUX (PTY) LTD

RESDIDUAL DRAWDOWN ANALYSIS *BH 6484*

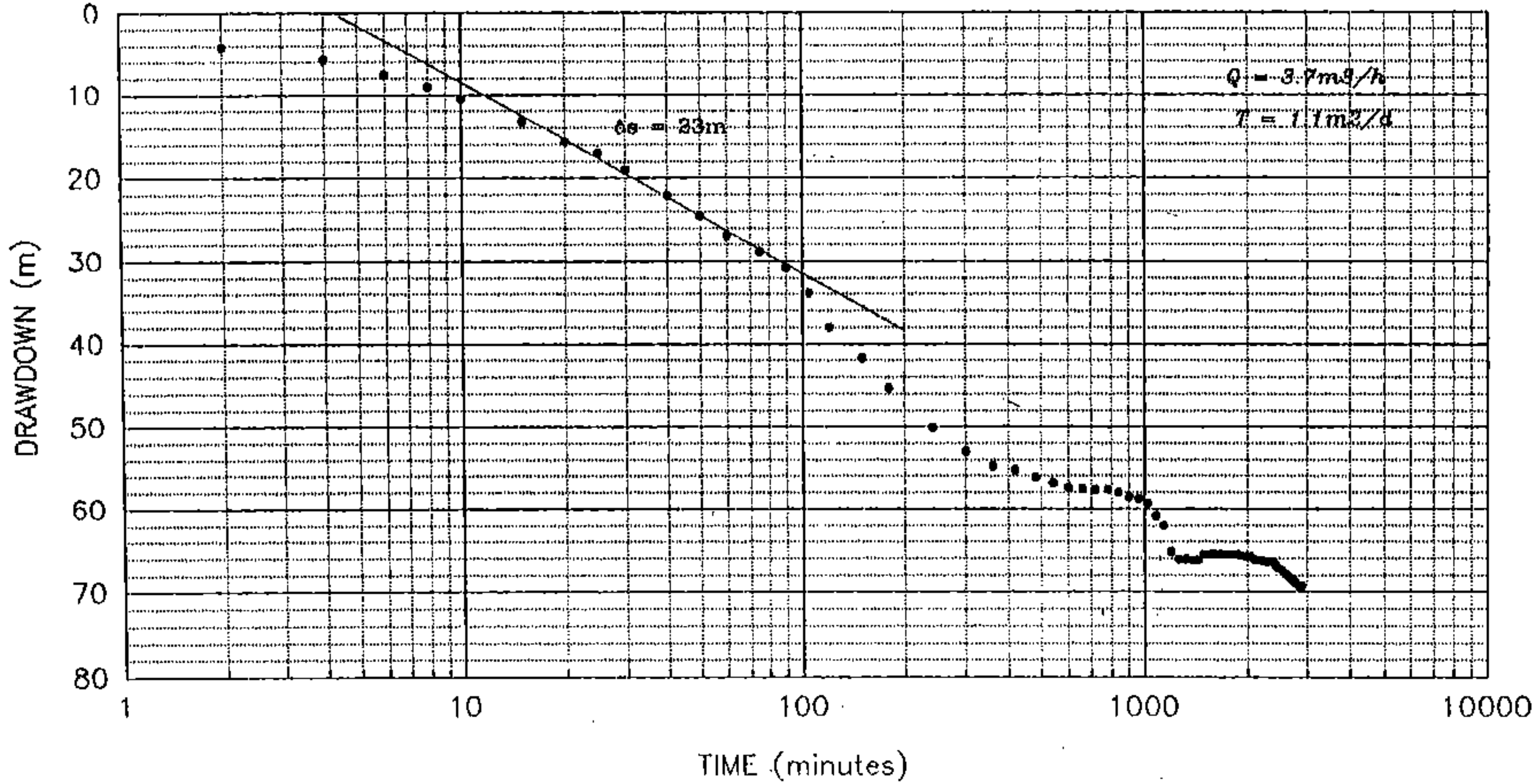
swl = 10.24m



GEOFLUX (PTY) LTD

LEKGWABE – CONSTANT DISCHARGE RATE TEST BH5448

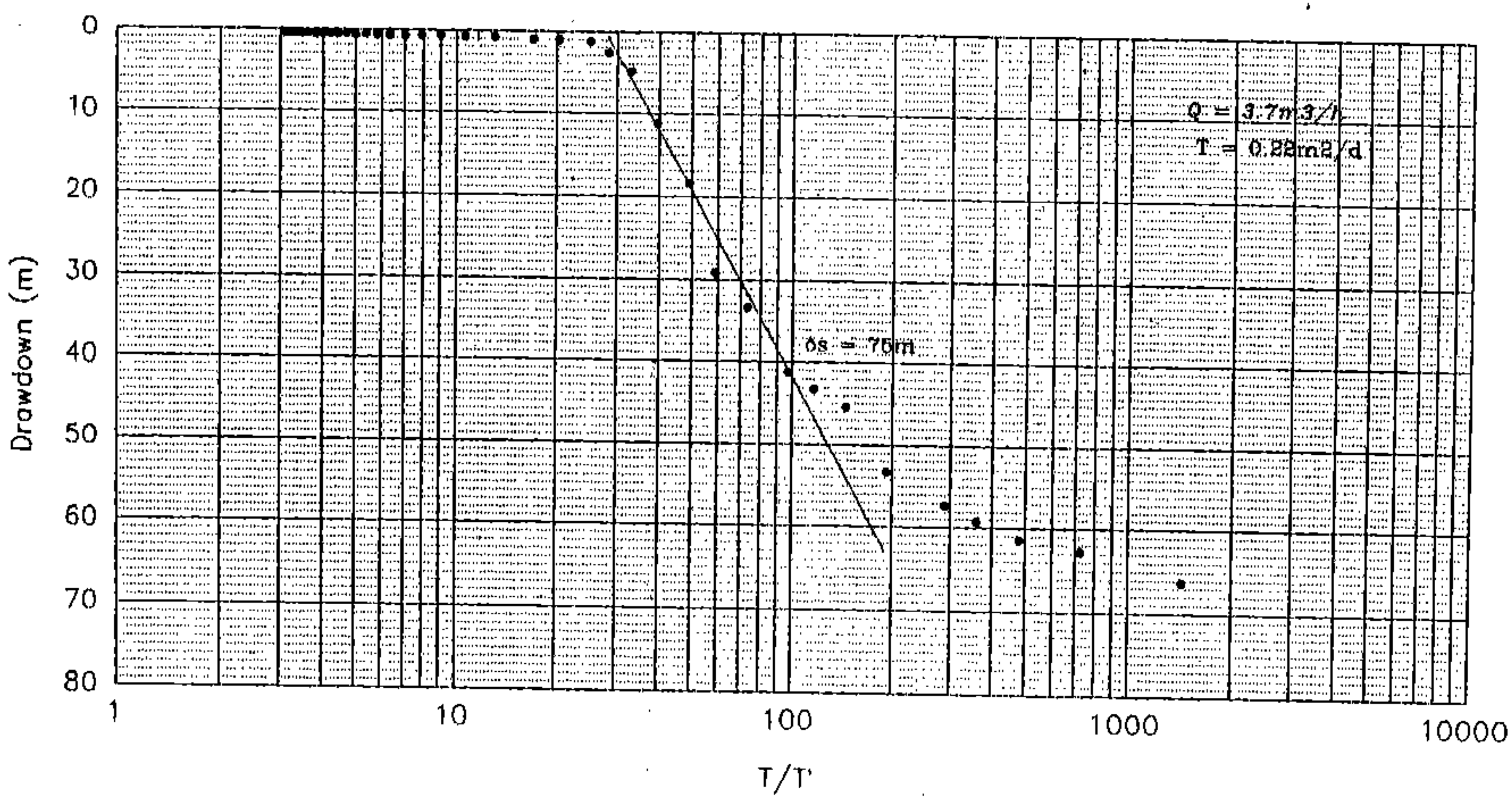
SWL 10.00 m



GEOFLUX (PTY) LTD

RESDIDUAL DRAWDOWN ANALYSIS *BH 5448*

swl = 10.00m



GEOFLUX (PTY) LTD